RAYTHEON COMPANY
Communications and Data Processing Operation
Norwood, Massachusetts

for period

June 19, 1964 through January 15, 1965

for

Contract No. NAS 8 11604
GSO No. 48064

REPORT ON PHASE I

Fast Scan Infrared Detection and Measuring Instrument

January 15, 1965

CONTENTS

ILLUSTRATIONS

ABSTRACT

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At the outset it was acknowledged that building an instrument which fully conformed to the contract requirements would require, as a minimum, break-throughs in the areas of Optics, Scan Design, and Detector Technology. Otherwise the ultimate resolution and temperature difference could not be achieved. Much time was spent in exhaustively evaluating a variety of promising techniques. As these were discarded, others would be investigated. Generally those techniques which could be easily implemented would be investigated. Experience gained as a result of these efforts has yielded three significant break-throughs which permit us to proceed with high confidence of success. These developments are in the fields of Optics, Scan System and Use of Detectors.

In the Optics, it was decided to design the system intentionally to the diffraction limit as the limiting dimension thereby eliminating spurious signals from coma-shaped field plots.

In the Scan System, a detailed study yielded the information that aberrations from a new and extremely unconventional scan system, the double helix, could be controlled to a smaller magnitude than more conventional systems.

In the use of Detectors, two developments were significant; the planning of an experiment using an IR optical fiber as a focal plane light pipe to the detector element, and the use of an extremely small detector acceptance angle-aperture combination to enhance sensitivity of the detector.

The technology has therefore been developed to enable us to continue to Phase II with full confidence that the contract's specifications will be met.

Axton

INTRODUCTION AND SUMMARY

In accordance with provisions of the referenced contract, there follows a report on the work accomplished in Phase I. This work has resulted in selection of techniques, parameters and design philosophy which will permit continuation to Phase II, the actual design and construction of a prototype for evaluation.

All major problem areas have been investigated and satisfactory solutions found. It is not anticipated that deviation from the specifications set forth in the work statement will be necessary.

The most critical development problems were associated with design of the microscope. It was therefore decided to concentrate on this since we are confident that if all of the major problems can be solved in the microscope, other target sizes will be relatively easy to cope with.

In microscope design a Pfundt pierced mirror system was chosen as providing the most easily workable arrangements of detector target and scanned elements. It was determined early that an optimum system would be near the diffraction resolution limit so it was planned to take advantage of this and conceive of a diffraction limited design over the full field. This rather bold approach provides the advantages, that if the diffraction limit can be achieved the spot size on the target will be the size and shape of the airey disc thus insuring uniformity in both the X and Y plane. Further it insures that radiation from the target is not affected by the geometry of the spot size. It is the fundamental invariant limit from which all other system variables can be taken.

A polygon helix scan with X axis and Y axis driven separately in synchronism by digital inputs to two separate stepping motors was chosen for the inherent accuracy the system is able to achieve at small scan distances and further for the flexibility available for a system of this type.

The detector study carried out indicated that microscope systems having narrow image entrance cones yield a configuration in which unusually high detectivities can be achieved providing the detector can be made background limited. There are of course drawbacks such as inordinately high detector impedances and consequent RC time constant problems, but techniques have been devised for minimizing these. Nonetheless values for detectivity have been chosen conservatively and still yield adequate signal to noise values.

Development effort on data processing has been primarily concerned with providing a workable system on a purchased parts basis. Recognizing however that the greatest benefits from the microscope system will yield from a versatile and adjustable readout system, emphasis on readout development has been toward providing the scanning electronics and also the detector amplifying electronics with an adequate population of information points to insure the availability of any data pickoff later required by the data processing.

There follows then a report of the work accomplished during Phase I, a description of the design which will be executed in Phase II, and toward the end of the report a section entitled "Anticipated Work" indicates broadly the work plan developed for Phase II.

ENERGY TRANSFER

The energy relationships involved in transfer of radiance information from the target into some usable form for the operator have been studied. Those parameters which it is believed will have a major contributory effect have been included. From these parameters a mathematical model has been derived as shown in Appendix I. Transfer of the information at the target to the operator can be considered as part of a train consisting of the following major elements: Optics, Scanner, Detector, Electrical Output.

It will first be assumed that a component in the image plane is emitting a fixed amount of radiation into a hemisphere. It will be the function of each of the subsequent elements in the chain to collect, channel and process this radiation.

Optics

The first function of the optical system is to collect energy from as large a solid angle from the component as possible. It is, therefore, incumbent on the optics to be as large in diameter and as close to the target as possible. Furthermore, the energy concentration from the target should be defined by the ultimate optical limit: the diffraction limit.

Optical efficiency can be defined as the percent of energy not absorbed by the optics and it is obvious that this quantity should be kept high.

The final function of the optics is to re-image the target on the focal plane of the detector in either minified or magnified form.

Neglecting transmission efficiency the ratio of the product of the collecting cone and the size of a target to the size of its image times its collecting cone is inversely related to their ratio of energies. Therefore, if a system is energy limited, the amount of magnification used should be only that necessary to image a small spot size on a detector of usable area.

Scanner

The effect of the scanner is to sequentially inspect one resolution element on the target after another in such an order that information can be usefully retrieved. The image of the detector should remain on each spot for at least one detector time constant. This, therefore, establishes the bandwidth, the frequency of scan and the number of scanned elements within the time constant limits of the detector.

Scan efficiency can be defined as the active duty cycle or the percent of time the detector image is focused on useful target area. Therefore, the size, shape and frame rate of the scanned area is a matter of settling the trade-offs arithmetically.

Detector

The interrelationships of detector parameters are described in the literature (R.C. Jones, IRIS, 1958, 1961, 1962, et al) and have been reviewed elsewhere in this contract. The basic parameter with which we are here dealing will be detectivity (D*) which is the resultant value of the other variables. The conversion of energy to electrical voltage is done at the end of the train by a function called <u>responsivity</u> which is an experimentally verified parameter which differs with each detector.

The interrelationship of these variables can be seen below in equation form. Derivations can be found in Appendix I.

TARGET ϵ, TB	$As\epsilon\sigma T_B^4$	OPTICS	SCANNING MECHANISM	DETECTOR CHARACTERISTICS	$\frac{Ps}{PN}$	$\frac{(S)}{(N)}$
BACKGROUND ϵ, TA	$As\epsilon\sigma T_A^4$					

$$\frac{S}{N} = \frac{As \sin^2\theta \; t_t \; Ee \; (T_B^4 - T_A^4)}{\underset{(1 \text{ CPS})}{NEP\Delta f^{\frac{1}{2}}}}$$

WHERE: As = Area of the radiation source (cm^2)

ϵ = Source emissivity

σ = Stephen - Boltzman constant (5.6686×10^{-12} WATTS/cm^2/deg K^4)

TB = Temperature of target B (^oK)

TA = Temperature of surrounding background (assumed to be ambient)

$As \frac{\sin^2\theta}{2}$ = Solid angle within which the radiant energy is collected

t_t = Transmissivity coefficient: due to various transmission losses

E = Efficiency of the scanning mechanism (Total bits/sec $\div$ target bits/sec)

f = Frequency of the target sampling rate (Total bits/sec 2)

e = Detector aperture efficiency (fixed area As and solid angle $\underline{\sin^2\theta^1}$)

M = Magnification

NEP = Detector NOISE Equivalent Power (WATTS/CPS$^{\frac{1}{2}}$)

$$\left(\frac{S}{N}\right) = \sigma\epsilon \frac{(T_B^4 - T_A^4)}{NEP\Delta f^{\frac{1}{2}}} \times As \; \underline{\sin^2\theta} \quad t_t \quad Ee$$

$$\left(\frac{S}{N}\right) = \text{System Independent Parameters X System Dependent Variables} = K_1 \& K_2$$

DETECTORS

A comparison was made (Appendix II) of the best available detectors for the infrared microscope and it supports the viewpoint that for the wide range of applications contemplated for the device two different detectors will eventually be necessary. The first detector will feature the ultimate in detectivity for the smallest spot size although it is less convenient to use.

The second detector for large spot size operation requires none of the trauma associated with liquid helium and, therefore, appears attractive. The primary objection to its use in the microscope context is that the detector sensitive area cannot be reduced to the .003 inch diameter necessary for the microscope image without incurring major electrical problems in the form of increased detector time constant.

The above is a judgment based on the appended report which shows a few things about the two types of detectors which are significant.

The predominating characteristic of these detectors is their sensitivity to background. Background can be defined as any radiation detected by the sensitive element which is not radiation from the target. Background can be in a variety of forms, for example, energy emitted from the optics or from a spectral region in which the target does not emit. Great care has been taken in the design of the system to limit the amount of background radiance seen by the detector.

Sensitivity is also a function of detector aperture. Best sensitivity is achieved when detector aperture is small but energy considerations limit the minimum diameter to about .003 inch. Larger numbers for D* are available with smaller apertures but detector impedance becomes unworkably large. The order of magnitude of impedances is shown in Appendix II and practical values of impedance should not exceed 50 megohms for two reasons. The first is that signals reflecting this impedance are extremely difficult to handle, also the RC time constant of the detector circuit is increased. Trade-offs can be established experimentally for scan time versus small spot size, but in general it will be found that for the order of 50 meg impedance the RC time constant will be on the order of 10 microseconds thereby necessitating a reduction by 10 in scan time.

The effect of this can be minimized, however, and impedances reduced to more workable values in the copper doped detector since its impedance is reduced with increase in bias values. It is, therefore, possible to obtain reasonable impedance values and thereby good RC time constants by biasing the detectors at suitable levels.

For the feasibility breadboard model, it is proposed to use a Raytheon QKN1009 copper doped germanium detector now in our possession. The detector is a standard device and is amenable to modification for experimental purposes. Detector characteristics are listed below:

QKN Module No. 2, Mounted in QKN1009 No. 117

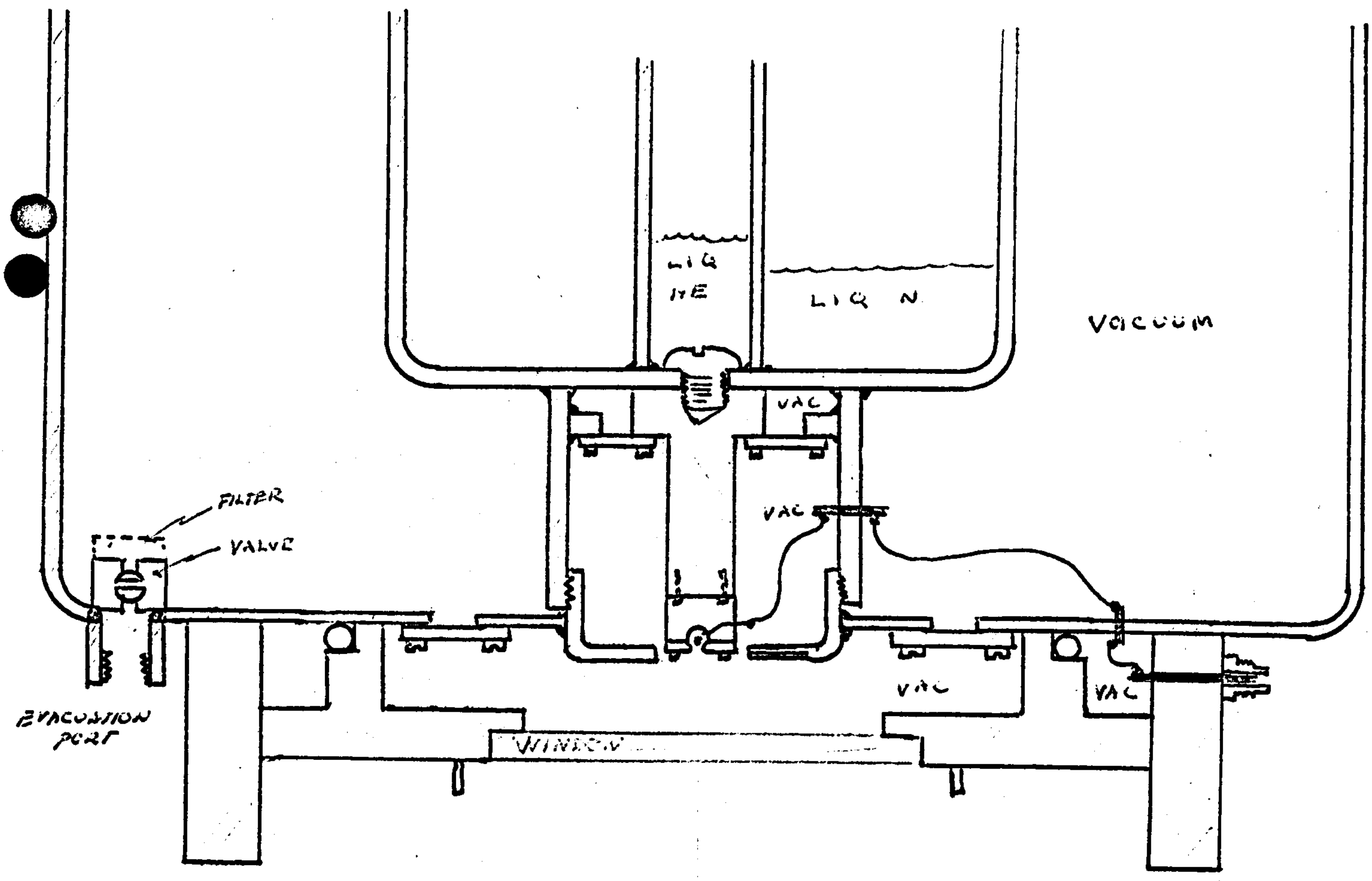
Material.......................	P-type copper doped germanium
Window Material................	Barium fluoride
Aperture Dimension.............	Effective aperture diameter -.003 inches (7.62×10^{-3} cm)
Aperture Area	7.06857×10^{-1} sq.in. ($4.5603 \times 10^{-5} cm^2$)
Aperture to Window Spacing (Inside edge of aperture to outside of surface of window).....................	.435 inches
Acceptance Angle.............	13.28 degrees total angle
D* (500,900,1) $300^{o}K$ Background Temperature......	$-2 \times 10^{+12}$ cm cps watt
Operating Temperature........	4^{o} K. Liquid Helium

Figures 1 and 2 show a sketch of the breadboard protype in its existing form and Figure 3 indicates a possible extension of this into a final form to make it compatible with the optical system.

Figure 4 shows an experimental aperture consisting of a single IR fiber having outside coating which limits its acceptance angle. This aperture is interchangeable with the window and clear aperture for experimental purposes.

By taking data first with a clear aperture and then with the fiber aperture it will be possible to quantitatively establish the value of the fiber as an optical element in an infrared microscope.

QK 1009



window 2mm thick 19 mm dia

Fig I

22 July '64
P. Chunko

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

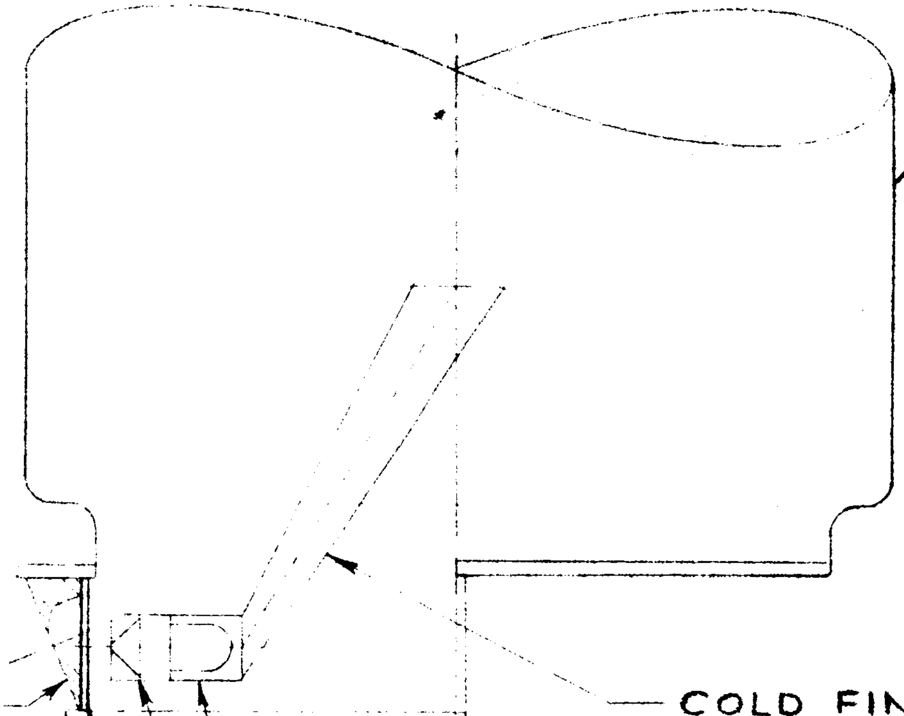


Fig 3

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ON DECIMALS
.X ± .XX ± .XXX ±
ANGLES: ± FRACTIONS: ±

MATERIAL:

CONTR NO.

DR	[illegible]	1-13-65
CHK		
APPD		

APPROVED

BY DIRECTION OF

RAYTHEON

RAYTHEON COMPANY
LEXINGTON, MASSACHUSETTS

DETECTOR ASSEMBLY

SIZE	CODE IDENT NO.	
A	49956	4410290209-2

SCALE 1 : 1 SHEET 1 OF 1

10—0700 VELLUM

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

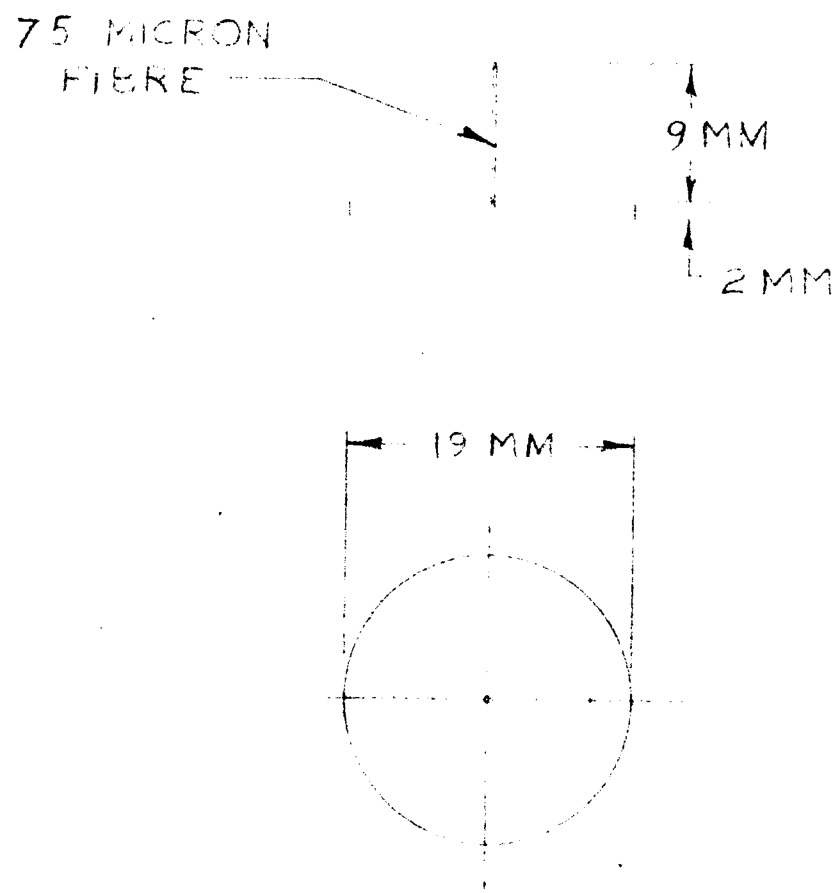


Fig 4

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ON DECIMALS
.X ± .XX ± .XXX ±
ANGLES ± FRACTIONS ±

MATERIAL

CONTR NO.

DR 1-11-65

CHK

APPD

APPROVED

BY DIRECTION OF

RAYTHEON

RAYTHEON COMPANY
LEXINGTON, MASSACHUSETTS

FIBRE RELAY ASSEMBLY

SIZE	CODE IDENT NO	
A	49956	4410290209-1

SCALE 2:1 SHEET 1 OF 1

10—0700 VELLUM
FORM NO. 10—0701 GRID VELLUM

OPTICS

From the options suggested in the August monthly report, an optical system has been selected that should provide sufficient image quality to achieve specified spot sizes in the microscope context. Furthermore, several schemes for power changes have been suggested but these have not been investigated as thoroughly. The microscope objective uses a first surface aspheric mirror as its basic starting point.

This system is designed to provide the highest performance level at a magnification ratio of 7.62 to 1.0. A first approximation algebraic solution has been accomplished which indicates that the system will require a moderate aspheric profile in the mirror surface in order to reduce the spherical aberration and a minimum of one set of correcting elements in order to eliminate the off-axis coma.

Then, in order to provide the one-to-one imagery and the three-to-one imagery, for targets of 0.25" and 1.0" x 1.0" respectively, it will be necessary to introduce two separate, primary imaging systems to perform the initial de-magnification. The basic mirror system plus correcting refracting elements will, of course, provide the final imaging function, focusing the energy on the detector.

Technical Considerations

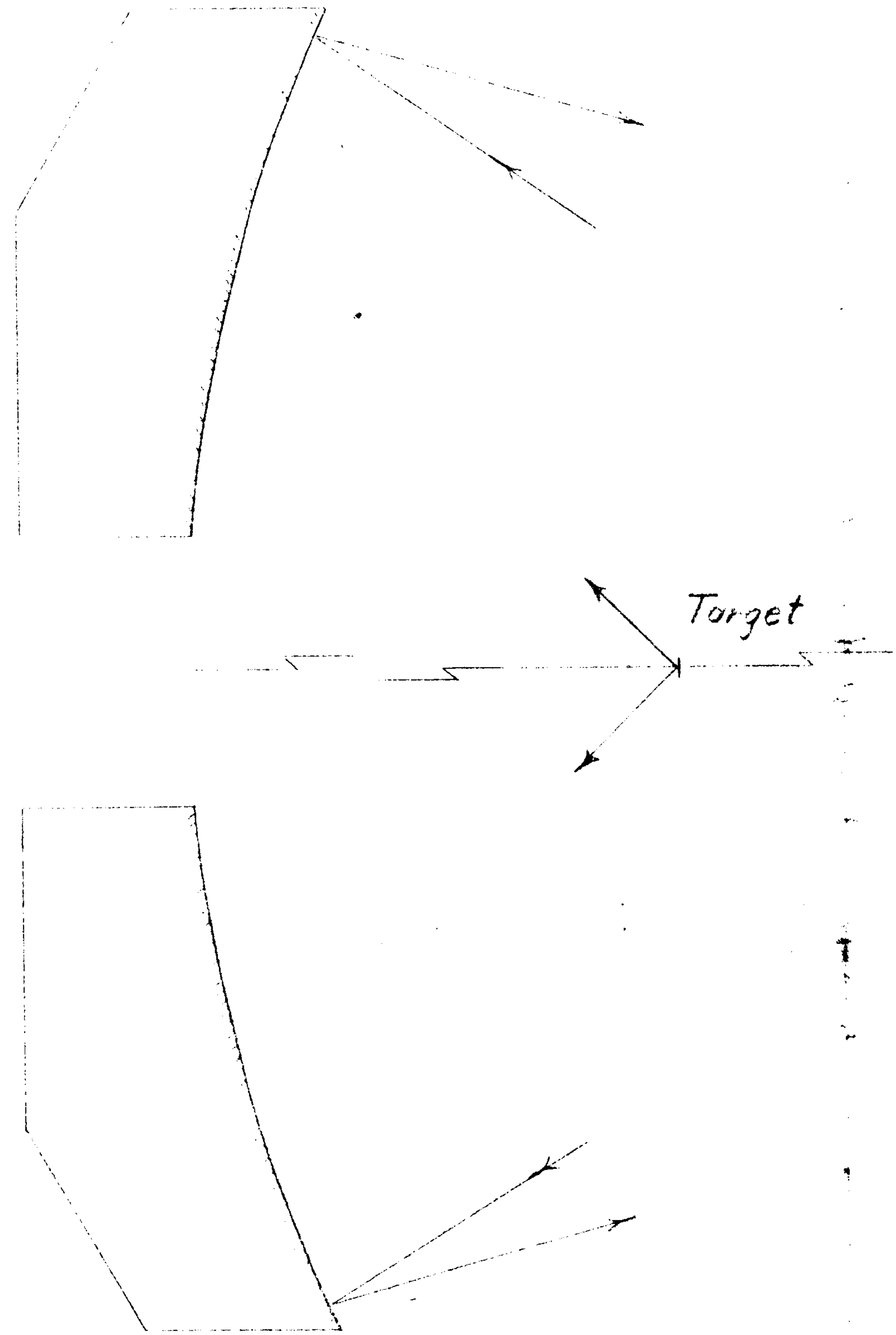
If we assume that the 7.62 to 1.0 system is the basic unit we have the following nominal parameter values:

1. Diameter of primary mirror --- 200 mm
2. Target distance --- 260 mm
3. Image distance --- 1980 mm

Conceptually, there is an excellent rationale for the large diameter of the optical system for the microscope. Diameter is one of the most powerful means of controlling the diffraction limit of a small field optical system. Using a diffraction limited optical system over the complete field of view yields a significant advantage: that of uniformity of radiance over the field. There are few other better means of engineering a system which can derive a uniform field plot over a 100 to 1 range off axis. It is naturally possible to obtain a uniform field plot by means of field flattening correctors (all reflecting) but the most elegant technique is to use an elipsoid on axis and try to get away with a diffraction limit over the full field. The blur or airey disc would then be uniform for the system.

One further advantage of this system is that it is very close to ultimate. The only means by which finer resolution can be obtained is by filtering to a different wavelength continuum or by altering the diameter of the primary. Short of obtaining a detector of vastly improved D* the system is reduced to these fundamentals.

This tentative configuration, showing a nominal set of correcting optics, fabricated of potassium chloride, is shown in Figure 5. In Figures 6 and 7 are shown typical examples of auxiliary types of optical systems to provide the required one-to-one and three-to-one imagery. While an all mirror type system is to be preferred, since it is completely color free, there are disadvantages in the forms of obscuration losses. Therefore, an alternative choice, using all refracting lenses is also illustrated. Both of these approaches require detailed analysis, however, to select the most suitable configuration for this application.


Target

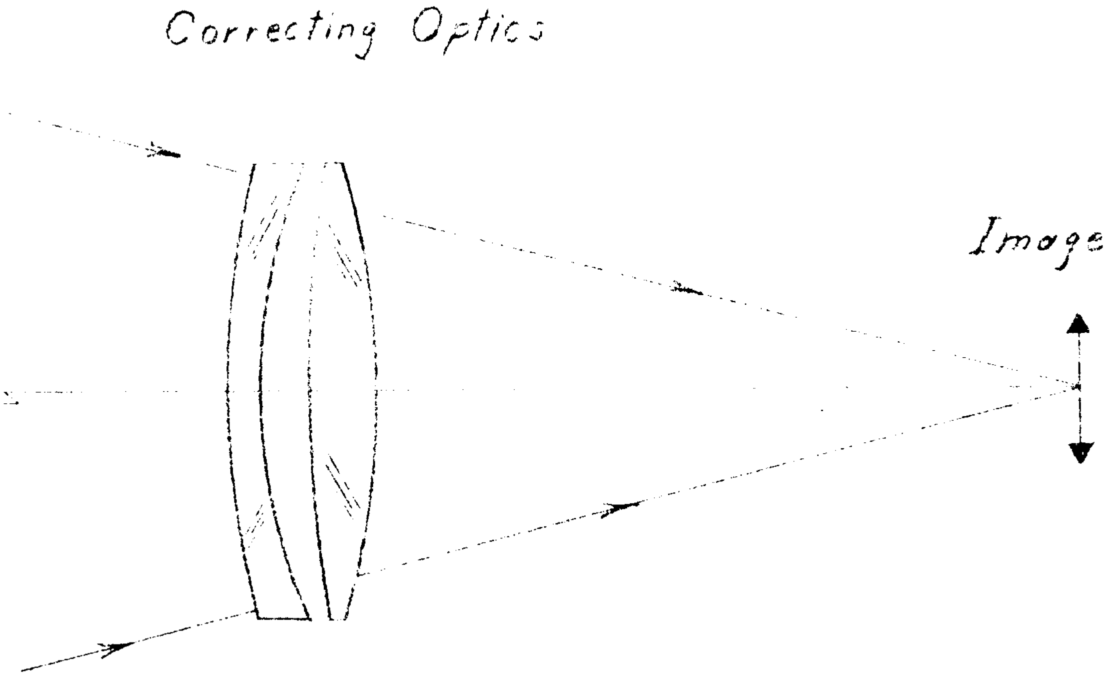
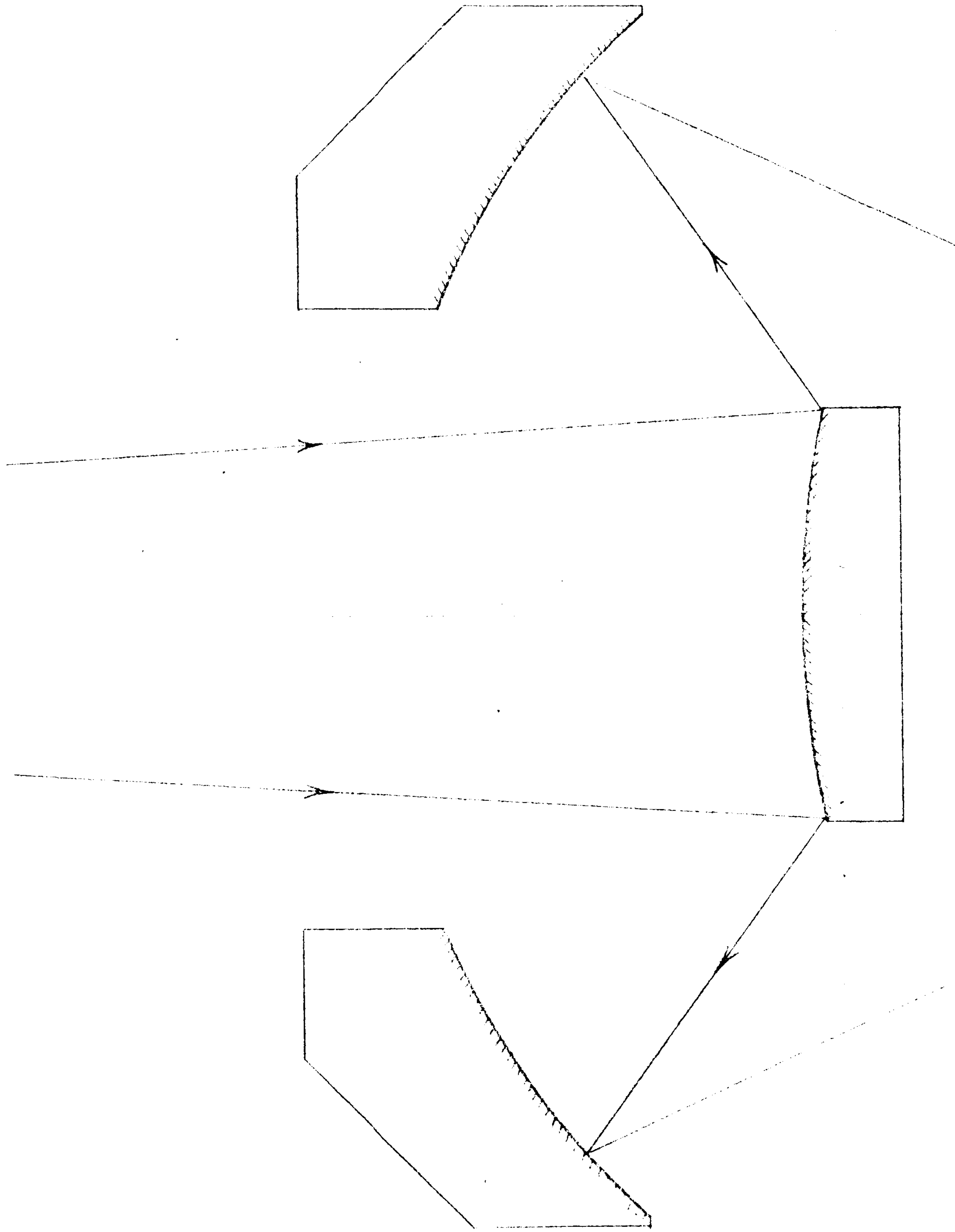


PLATE I

Fig 5



Auxiliary Reflecting Relay
Optical System

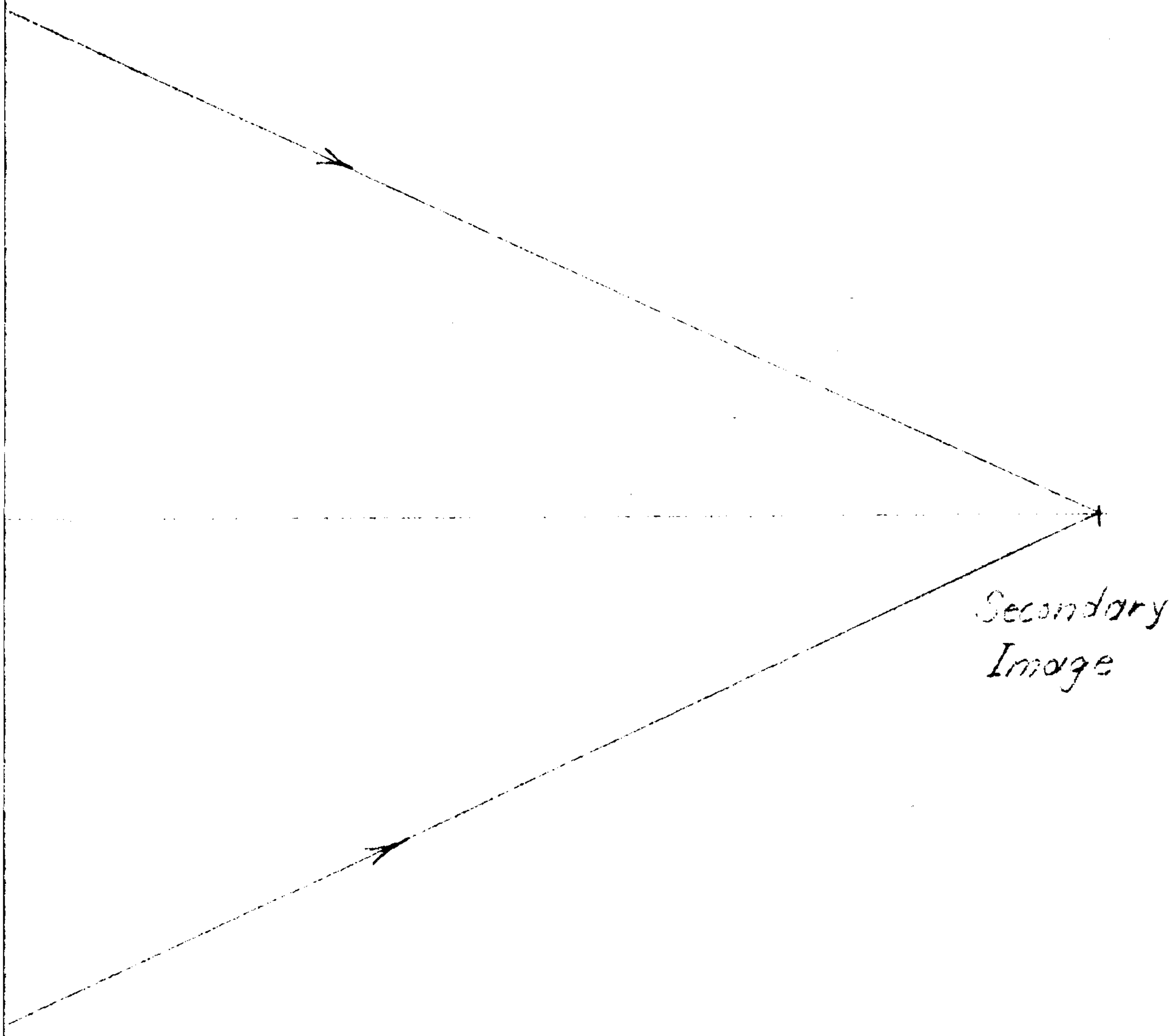
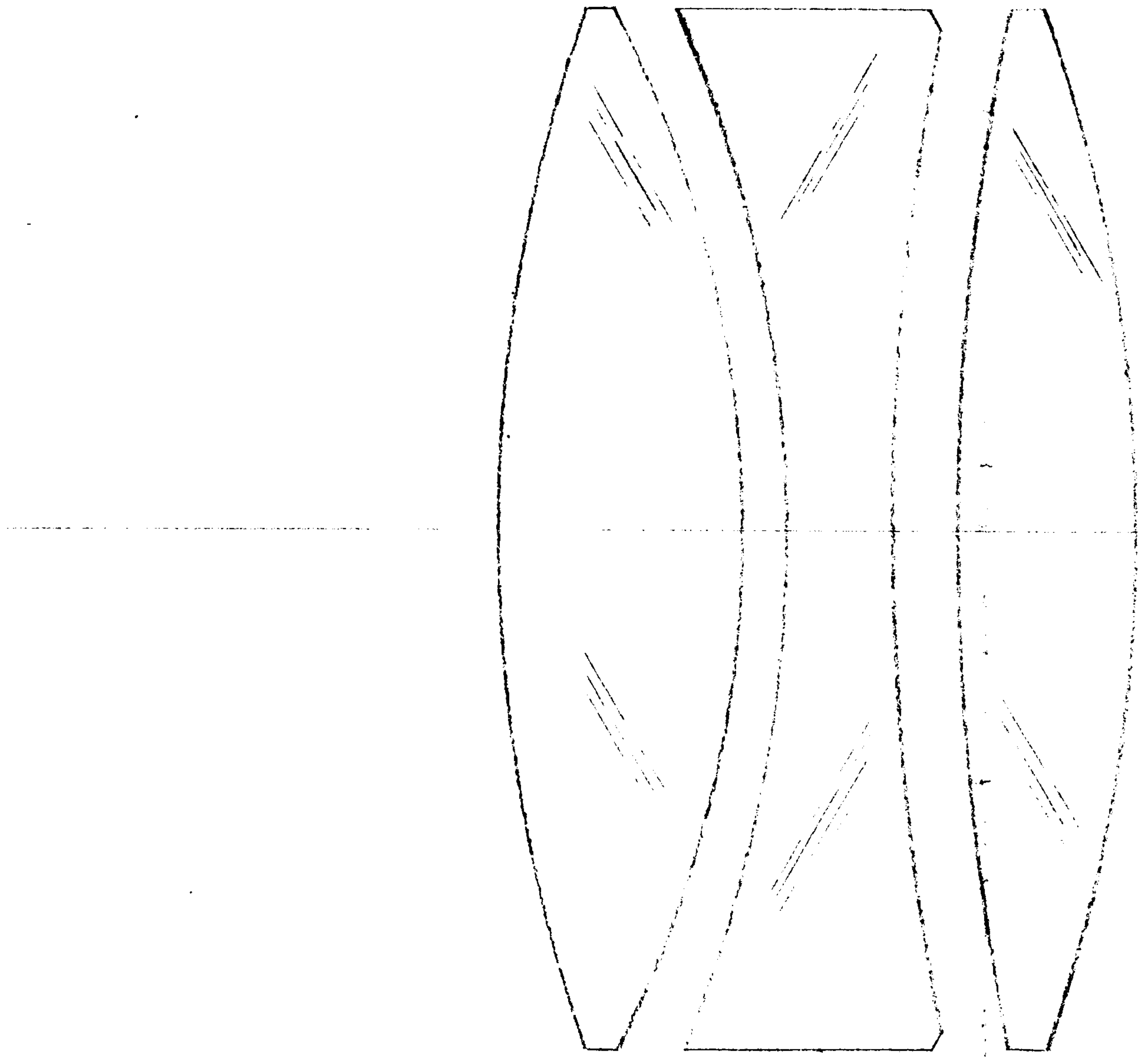


PLATE II
Fig 6



Auxiliary Refracting Relay
Optical System

PLATE III

Fig 7

SCANNING

After careful study of the available techniques for scanning out a raster pattern, a polygon-helix scan system was chosen (Figure 8). This scan provides the following extremely useful benefits for this system:

a. It is not position critical since it does not operate at the focal plane.

b. It is flexible, in that scan is controlled by adjustment of three separate motions.

c. It is all reflecting and introduces minimal optical distortion.

d. It is amenable to a variety of scan patterns.

The polygon-helix scan consists of two separate scan techniques: the double helix which translates the image of the target across the detector in a straight line and at constant velocity and the polygon which is an inverted reflector wheel.

Helix

The planes of the surfaces of both helices are normal to one another and revolving them has the effect of moving rays parallel without increasing the length of the optical axis.

A small amount of distortion is introduced owing to the fact that the traced ray deviates from a perfect orthogonal folding system by the pitch of the helix. Furthermore a helix is not a flat surface. A study was instituted to establish the degree of aberration introduced by the helix; it was found that dispersion of the order of one hundredth of a micron would occur at the focal point for 10-inch diameter helices in the configuration shown in Figure 8. The results of this study comprise Appendix III.

While the calculations indicate that dispersions resulting from this helix configuration tend to be of a magnitude which will not be troublesome, it is planned in Phase II before finally committing ourselves to this procedure to conduct a simple experiment. The experiment consists of fabricating sections of helix and mounting them (Figure 9). Blur circle measurements will then be taken with visible radiation of similar convergence and spot size for varying orientations of the test surfaces. After these tests are complete, fabrication will commence. Every effort will be made during this program to reduce the size of the helices.

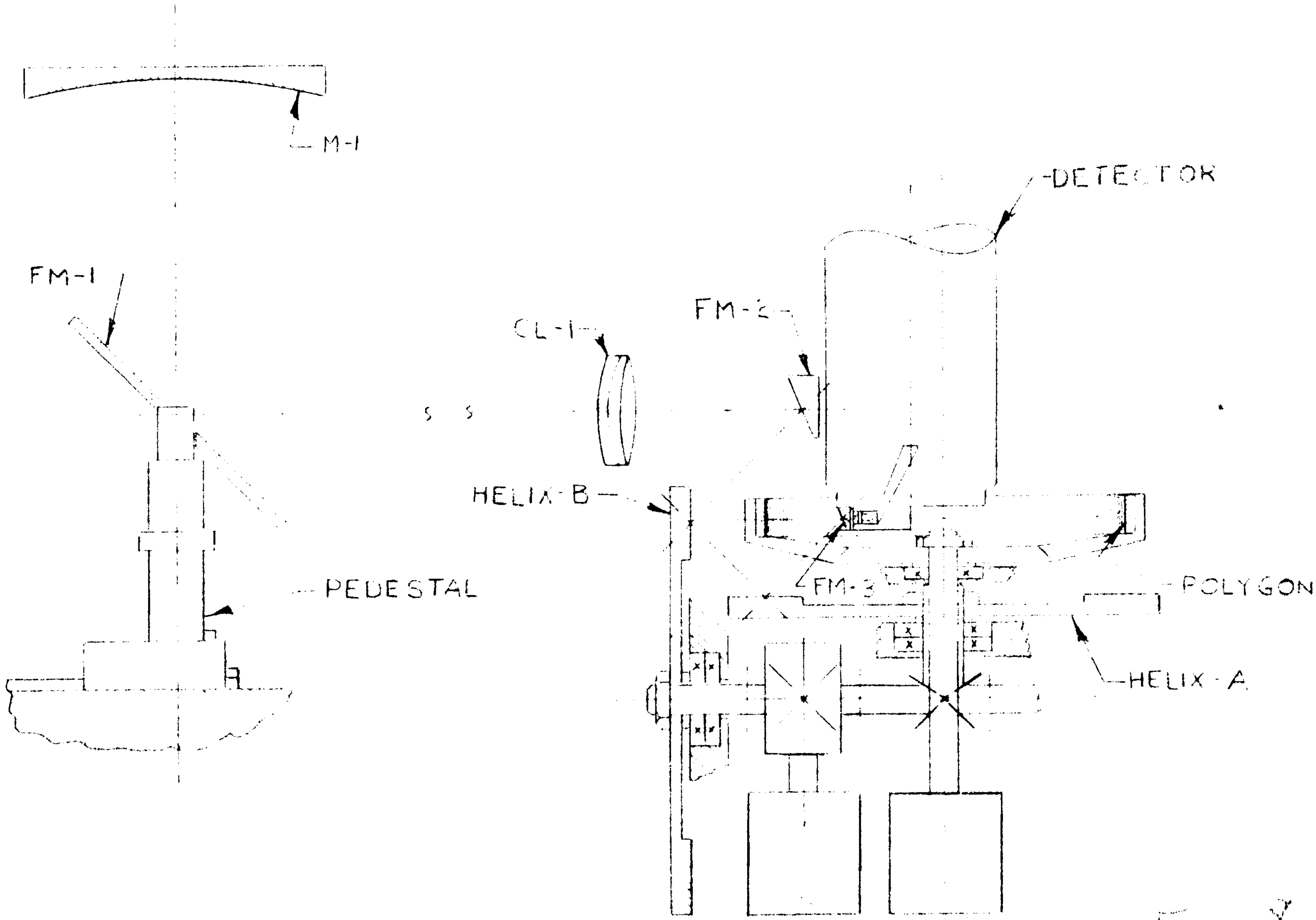
Polygon

The polygon shown in Figure 8 consists of 100 separately adjustable faces each oriented on a circle of radius 121.4 millimeters. Incoming radiation is folded onto the polygon surface in such a manner that the image plane is half way between the mirror surface and the axis of revolution. This regime uniquely provides a constant optical path length for each facet in the optical path.

Each facet is separated by an opening behind which is a black body reference source and a focusing ellipse. The function of this is to clamp the AC signal from the target to a fixed reference radiance at the end of each scan.

For each rotation of the polygon (or more properly the centagon) each helix rotates one time and one scan is completed. Motions of all elements are monitored by a scan code modulator attached to each rotating element. The scan code modulator will take the form of a series of apertures held in mechanical synchronism with the mirror facets and also with the step in the helix. Position information will be provided to a signal generator which drives a wide range stepping motor which imparts a motion through a gear train to shafts driving the helices and the rotor. The use of three motors incurs no great additional expense and yields the advantage that synchronism can be adjusted and experimentation carried on with optimum scan modes.

The drive and servo circuitry will be explained further in the section concerned with electrical signal.


M-1
FM-1
PEDESTAL
CL-1
HELIX-B
FM-2
DETECTOR
FM-3
POLYGON
HELIX-A

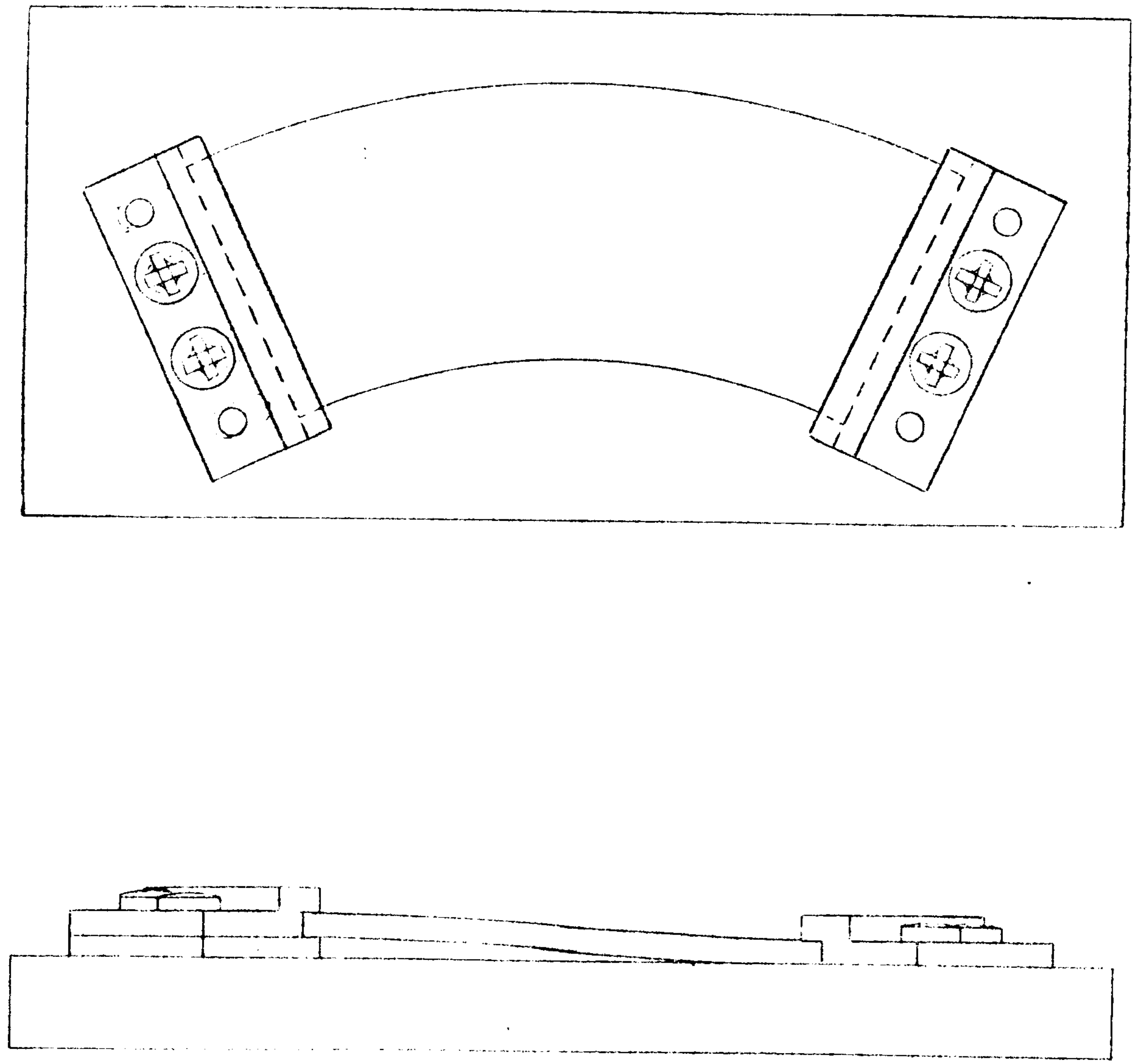


FIG. 9
ARC HELIX ASSY
EXPERIMENT

MECHANICAL DESIGN

The scan mechanism is presently conceived as an integral unit, schematically illustrated in Figure 10. This assembly will be located at an appropriately nominal distance from the target pedestal and objective mirror assembly, the distance being adjustable about the nominal to obtain proper focus at magnifications determined by pedestal position.

The assembly will contain an adjustable corrective lens, two frame scan helical mirrors, a segmented line scan mirror, the detector assembly including dewar flask, and any required folding mirrors. The various parts will be supported on a casting of sufficient rigidity to prevent undesired relative motion between elements of the optical path. Position adjustments in both radial and axial directions will be provided in order to eliminate excessive precise machining of the casting at helical mirror and detector locations. The axis of the segmented mirror will be fixed in position because of mirror size, complexity and positional stability requirements. The plane which includes this axis and the center of the corrective lens will be the fixed dimensional reference.

Several drive systems have been considered, but only the more obvious design details have been discussed. However, basic design parameters have been qualitatively stated. These include introduction into mirror design of the largest moment of inertia consistent with size as dictated by optical requirements and with cost of both mirror base and motor. This is done to counteract the effect of any unforeseen transients which may occur in the drive power source and intervening linkage. Viscous friction losses will be minimized by using such basic shapes as discs and cylinders, and by maintaining reasonably low bearing peripheral velocities consistent with rigidity requirements. Direct drive is favored over gears because of the inherent impact transients and nonlinearities in spur gears and the very high cost of precision spiral gears. However, the convenience of a precision differential used as a control signal coupling device is very attractive, and remains under consideration. The requirement that the segmented mirror must be a "see through" device indicates requirement of either capstan or other reliable constant speed periphery drive. Otherwise, relatively thin-section spokes will be required and will result in increased windage power, a larger motor, and the possibility of harmonic rotational modulation at the natural frequency of the spokes.

In the event that direct drive of helical mirrors is used, the shafts will probably be cantilever supports for the mirrors (Figure 8), but will be designed for critical speeds at least six times maximum scan speed requirements. Dynamic balance of all rotating members will be assured. The probability of outboard shaft support has not been overlooked, especially when diameters greater than ten inches are considered. All static supports will be designed for maximum rigidity under dynamic loading and for long-term static stability at a temperature of approximately 75^{o}F.

In the event that indirect drive by gears and shafts are used, gear tooth and torsional modulation will be given special attention. Bearings will be self-aligning ball types, the probable exception being the support bearing for the segmented mirror when peripheral support is used. This bearing will probably be an extra light, large diameter thrust type considered as an aid to prevent lifting due to centrifugal action of the balls at higher speeds.

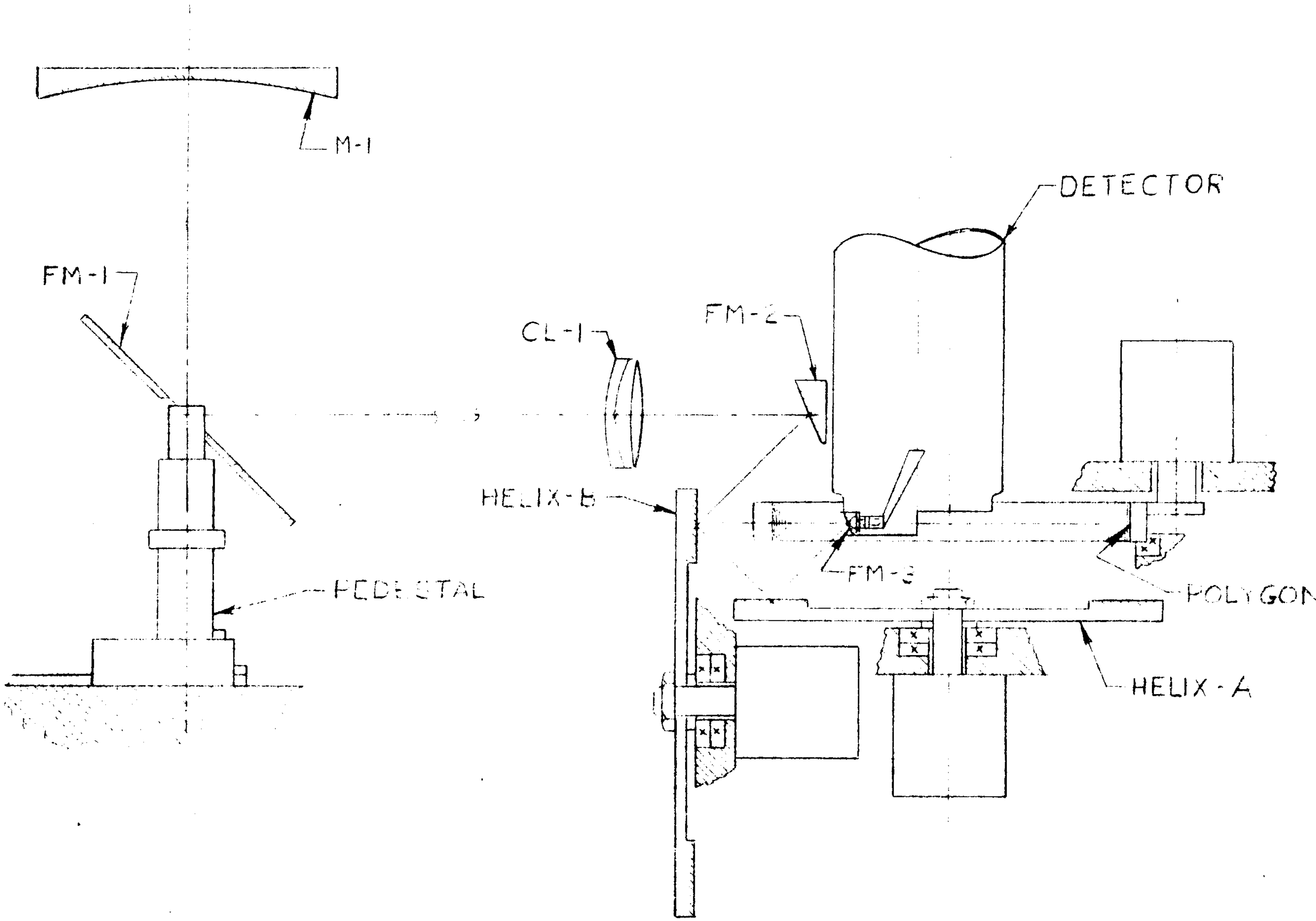


Fig. 10

ELECTRONICS

The Infrared Microscope consists of the following subsystems: Optics, Signal Amplification, Scan Drive, Mode Function, Data Storage and Recording, and Recorder Control and Display Systems interconnected to provide maximum flexibility. The block diagram for this is shown in Figure 11.

Signal Amplification System (Sweeping)

This system is driven by a dual element detector whose bias and load resistance is adjustable. The output of the dual element detector is applied to a differential input of a "Tekt" 122 Low Level Preamplifier. The output of the preamp is applied through an attenuator to one of the differential inputs of a second "Tekt" 122 Low Level Preamplifier. The output of the second preamp is connected to the Mode Function switch and a compression circuit.

The compression circuit develops a DC voltage which is fed back to the second differential input of the preamp. This produces an amplifier whose output is a logarithmic function.

Signal Amplification System

The output of the first differential preamp is fed to the input of a log amplifier of Raytheon design. The output of the log amplifier drives a VTVM calibrated in degrees centigrade.

Scan Drive System

The rotating element speed is controlled by a "Digitork" motor driven over the range of 144 to 1440 steps per second. This rotation is applied to a differential gear through a three-to-one step down. The differential gear has its spider gears driven at three selected speeds of 0 RPM, 10 RPM and 100 RPM to give us an output speed range of .6 to 6 RPM, 6 to 60 RPM and 60 to 600 RPM. Appendix IV contains a brochure describing the Digitork motors.

Drive for the Digitork motors is nominally accomplished by a pulse drive circuit which generates square wave pulses of proper amplitude and spacing and at a frequency corresponding to the desired motor speed.

It is planned to use two such motors, one driving the helix pair and one driving the polygon. For normal scanning patterns all of these elements rotate at the same RPM but drive of the two scans was separated to permit a greater latitude of scan configurations. For instance, with the polygon rotating at 1/4 the speed of the helices, 25 lines would be scanned across the full field rather than 100.

Figure 12 shows a schematic of the scan drive logic. A pulse driver generates signals of proper shape, pulse duration, and frequency and this is fed into the program logic block. For normal operation, no operation is performed on this signal at this point except that it is divided and identical signals are sent after suitable amplification to the helix motor and the polygon motor. Information on position of both the helix and the polygon are obtained through use of digital shaft position encoders which feed position information back to the logic modules. The polygon speed is fixed and as close to linear as possible.

If the helix is slow or fast with respect to the polygon, a signal is generated in the logic module which slows or speeds up the helices until they are once again in synchronism. One function of the program logic module, therefore, is to act as a digital servo.

Other functions of the logic module are to change scan rate, change X scan rate with respect to Y scan rate and permit manual scan and inspection of one line at a time. These different operations are controlled by the program setup panel from which the complete scan system is controlled.

Mode Function System

The Mode Function System consists of signal switching matrix for selecting the following Mode Functions:

1) H.F. Signal Display: This parameter presents the signal and sync directly to the display unit for visual presentation.

2) H.F. Signal Record: Presents the signal and sync directly to the tape recorder for storage of the information.

3) H.F. Signal Record and Display: Combines Functions 1 and 2 for simultaneous viewing and storage.

4) H.F. Signal Playback and Display: Presents the information from the tape recorder to the display system for viewing the stored data.

5) H.F. Signal Playback and Write: Presents the information from the tape recorder to the chart recorder for permanent recording of the stored data.

6) L.F. Signal Record: Presents the signal and sync to the tape recorder for storage.

7) L.F. Signal Playback and Display: Presents the information from the tape recorder to the display system for viewing of the stored data.

8) L.F. Signal Write: Presents the signal and sync directly to the chart recorder for permanent recording of the data.

9) L.F. Signal Horizontal Line Display: Presents signal and sync for a single line to the display unit for viewing.

10) L.F. Playback and Write: Presents the information from the tape recorder to the chart recorder for permanent recording of the stored data.

Definitions: H.F. Signals are signals which are generated at sweep speeds greater than 50 RPM.

L.F. Signals are signals which are generated at sweep speeds less than 50 RPM.

Data Storage and Recording System

The Data Storage and Recording System consists of a tape recorder (Sanborn 3907A) and chart recorder (Sanborn 4500) whose signals are controlled by the Mode Function switch and functions are controlled by the recorder control switch.

The purpose of the system is to store the data for subsequent display either on a one to one time base or as great as thirty-two to one time base compression and/or permanently recording the data either on a one to one time base or as great as thirty-two to one time base expansion.

Recorder Control Switch System

The purpose of this system is to control the functions of the tape and chart recorders and to provide the power to the unit under test when the recording systems have reached operating conditions.

Control Parameters

1) 1 7/8ips to 60ips: Remote control of tape recorder speed.

2) .25ips to 100ips: Remote control of chart recorder speed.

3) Stop: This control will stop the record, play, fast forward and reverse of the tape recorder -- the run of the chart recorder and will remove power from the unit under test. This control is interlocked with the footage control of the chart recorder to stop the system when the chart paper runs out.

4) Fast Forward: Remote control of the fast forward function of the tape recorder.

5) Reverse: Remote control of the reverse function of the tape recorder.

6) Play: Remote control of the play function of the tape recorder.

7) Play and Write: This control will start the chart recorder at a speed of .25ips and the tape recorder at the selected play speed. After four seconds, the chart recorder will switch to the selected writing speed.

8) Make Test and Write: This control will start the chart recorder at .25ips. After four seconds, it will switch the chart recorder to the selected writing speed and energize the make test control relay.

9) Jog: Remote control of the jog function of the chart recorder.

10) Make Test and Record: This control will start the tape recorder at the selected recording speed. After four seconds, it will energize the make test control relay.

11) Make Test and Display: This control will start the display system. After four seconds, it will energize the make test control relay.

Display System

The Display System consists of three subsystems for viewing field scan, selected line scan and selected spot of a selected line scan.

Field Scan: The field scan system applies the signal to the "Z" axis of the oscilloscope through a variable gain amplifier to intensity modulate the beam of the oscilloscope. The vertical and horizontal sync signals are applied to the "X" and "Y" axes of the oscilloscope to provide a raster in sync with the incoming data.

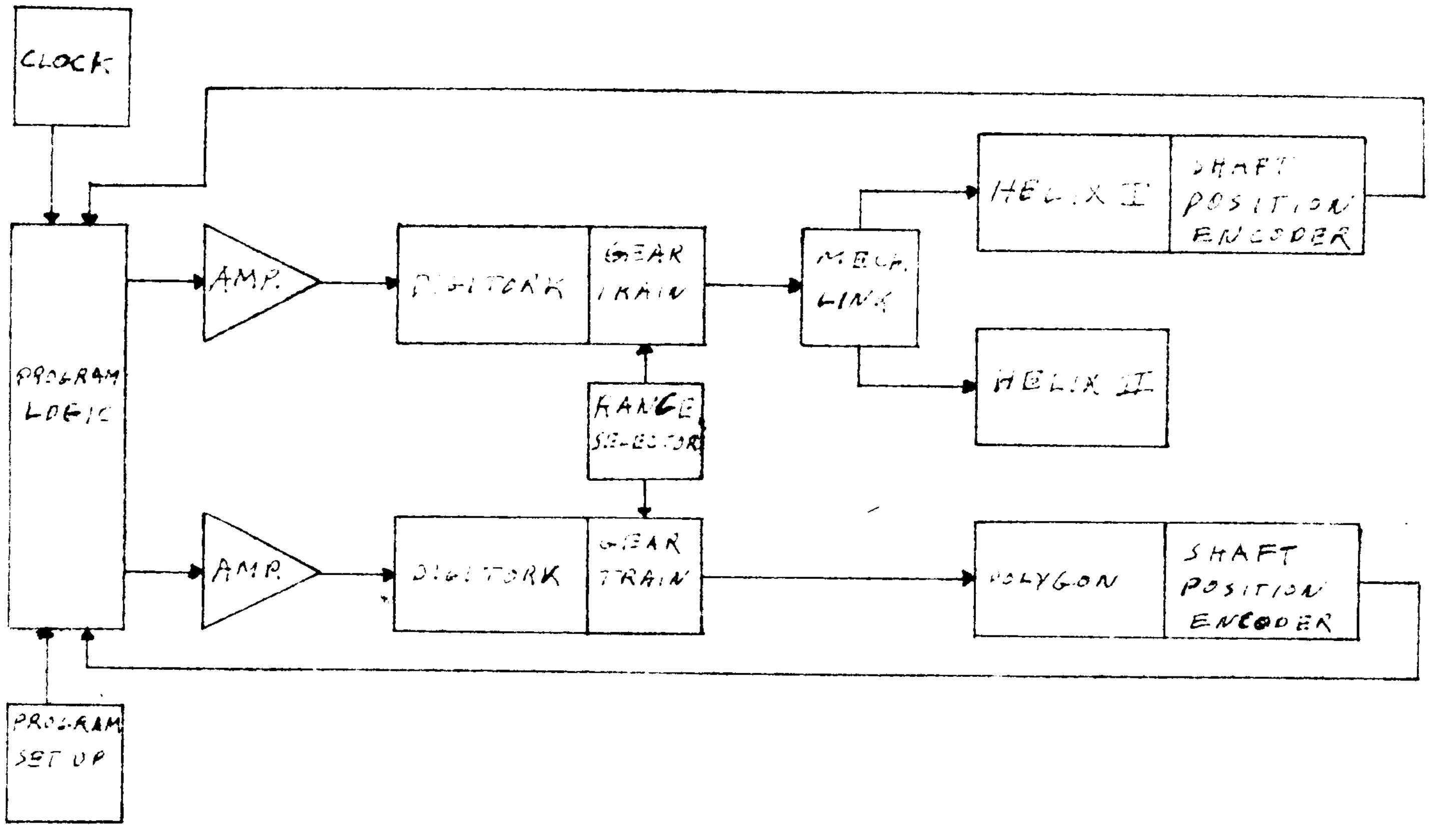
Selected Line Scan: The selected line scan system applies the signal to the "Y" axis of the oscilloscope through a gated analog switch. The horizontal sync signal is applied to the "X" axis of the oscilloscope.

The time at which the gated analog switch is turned on is a function of the amplitude change of the staircase signal (vertical sync). The staircase signal is applied to a differential amplifier with an adjustable reference. When the amplitude change crosses the reference set up in the differential amplifier, the amplifier triggers a flip-flop. The pulse generated by the flip-flop drives the set input of a set reset flip-flop turning it on. The output of this flip-flop turns the gated analog switch on.

The sawtooth signal (horizontal sync) is used to determine the end of a line. The sawtooth signal is applied to a Schmitt trigger. The trailing edge of the output pulse of the Schmitt trigger drives a pulse generator. The output of the pulse generator drives the reset input of the set reset flip-flop turning the flip-flop off in turn turning the gated analog switch off.

All lines can be sequentially viewed by turning the gated analog switch on manually.

Selected Spot of a Selected Line Scan: The selected spot of the selected line scan system applies the signal from the output of the selected line analog switch to the "Y" axis of the oscilloscope through a gated analog switch. The position of the spot that is sampled is determined by the amplitude of the sawtooth signal (horizontal sync). The width of the sampled spot is determined by a one-shot multivibrator whose pulse width is adjustable which turns the gated analog switch off. The spot presentation is a bar varying along the "Y" axis of the oscilloscope. At all time other than the selected spot time, a variable bar is presented for use as a reference for the selected spot to any other spot in the line and/or the same selected spot in any selected line.



SCAN DRIVE SCHEMATIC
Fig 12

ITEM	MODEL	INPUT IMPED-ANCE	OUTPUT IMPED-ANCE	INPUT LEVEL	OUTPUT LEVEL
Detector	Raytheon QKN-1009	-	-	-	-
Low Level Pre-Amp	Tektronix RM 122	10 Meg Ω 50 pf	1000 Ω	20 Mv (X1000) 100 Mv (X100)	20v p-p (X10 10v p-p (X1(
Log Amplifier	Barnes LA-3A	1 Meg Ω	2000 Ω	--	6v peak ma
VTVM	HP 400DR	10 Meg Ω 15-25 pf	-	.001 to 300 VRMS (full scale)	-
Tape Recorder	Sanborn 3907A	20 KΩ	100 Ω	.5 to 10V (direct) 1.2 to 5V (FM)	approx 6V (di approx 3V (F
Pre-Amp	Sanborn 656-2900	100KΩ	-	.625V/in	-
Optical Recorder	Sanborn 4500	-	-	-	-
Oscilloscope	Tektronix RM503	1 Meg Ω 47 pf	-	1 Mv/cm to 20V/cm	-
Power Supply	Tektronix RM 125	-	-	-	-
Paper Take Up	Sanborn 650-900 PTU	-	-	-	-

	GAIN	BANDWIDTH	SPEED	MISC	PRICE
	-	-	-	-	-
00) 0)	X100 X1000	.2 cps to 40 kc	-	-	$ 140
x	100 to 1000 (Pre-amp) 2500 (Oper Amp)	300 to 1200cps	-	-	400
	-	30 cys to 4.5 mcs	-	-	255
ect) M)	-	300 cys to 100KC (Direct) 0-10KC (FM)	60, 30, 15, 7-1/2 3-3/4, 1-7/8 ips	-	5680
	-	0-5KC (for a 4" Deflection)	-	-	2495
	-	-	100, 50, 25, 10, 5, 2.5, 1.0, .5, .25 ips	Chart width - 8" Chart lgth. - 200 ft. (normal) 350 ft. (thin)	3200
	-	d.c. to 450KC	-	-	655
	-		-	+ 135V @ 20ma - 90V @ 20ma - 6V @ 4	290
	-		-	-	570

ANTICIPATED WORK

In an effort to obtain every time advantage, long lead items will be procured by the end of January. Optical elements will be released for purchase prior to January 22, the experimental helix will also be purchased that week as will the first Digitork motor.

The mechanical design will be started simultaneously with optical design and completion will occur very soon after optical design is finished. There are apt to be some long lead time bearing assemblies and complex machining problems which will be released at the earliest convenient time. A heavy load of internal shop time has been scheduled for reasons of flexibility.

Electronic circuitry has been partially designed. Completion of this and purchase of necessary components will be of a lesser critical nature.

For a further expanded description of the anticipated work, see the program plan and its accompanying manpower overlay.

MANPOWER OVERLAY

Technical personnel participating during the current period are:

Name & Title	Current Period	Previously Reported	Total to Date
R. Vanzetti, Mgr. Quality Assur.	2.0	-	2.0
G. Mathis, Project Engineer	36.0	180.0	216.0
S. Bobo, Sr. Engineer Infrared	40.0	-	40.0
P. Chunko, Engineer	144.0	824.0	968.0
W. Bauke, Senior Engineer	-	86.0	86.0
M. Hinkle, Mathematician	243.0	176.0	419.0
R. Grant, Engineer	80.0	-	80.0
R. Gallipeau, Consultant	80.0	154.0	234.0
F. Orabona, Technician	144.0	80.0	224.0
J. Stoddard, Engineer	24.0	-	24.0
R. Powden, Technician	-	56.0	56.0
P. Debye, I-R Consultant	-	120.0	120.0
A. Krutchkoff, Engineer	-	40.0	40.0
	793.0	1716.0	2509.0

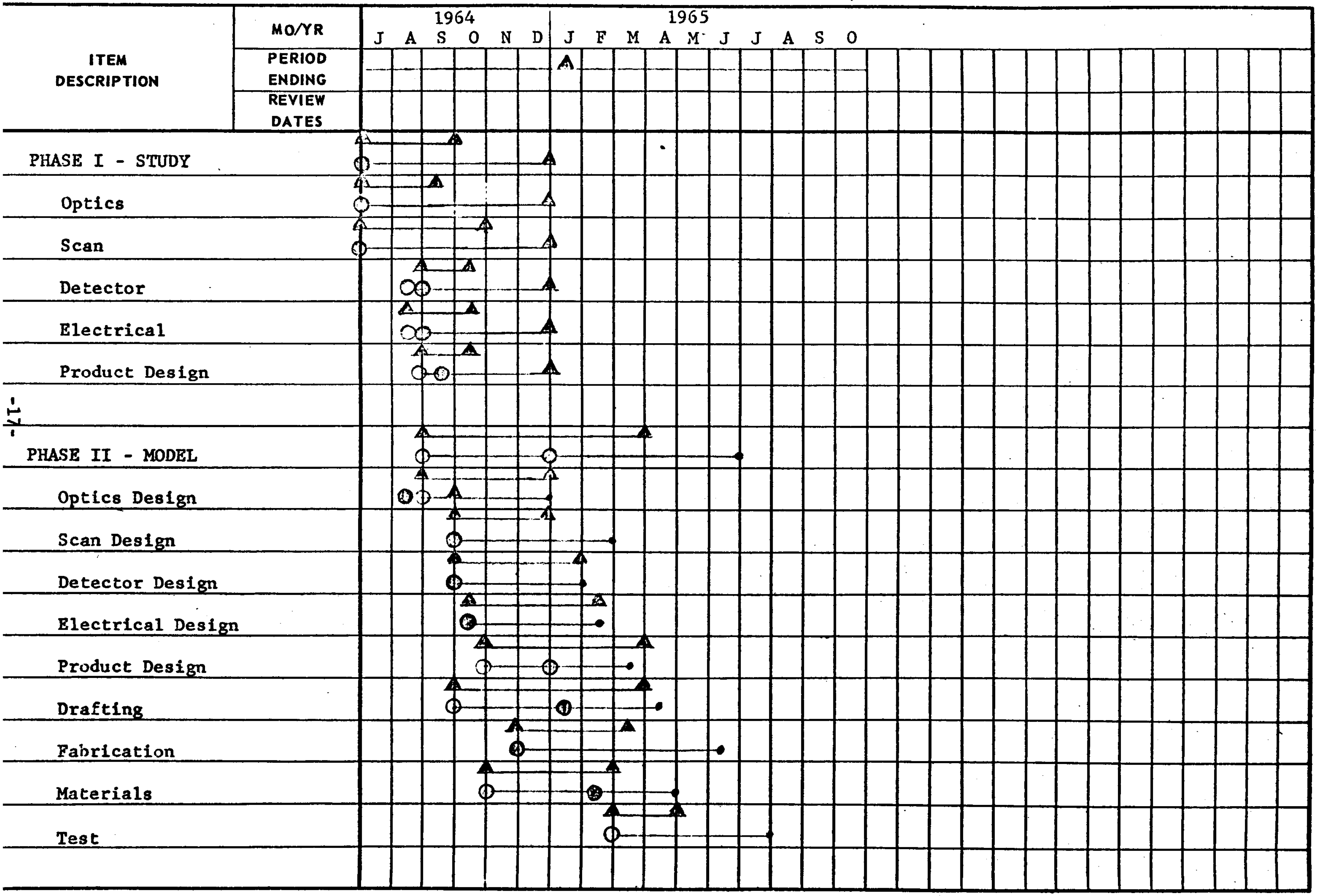
Rate of expenditure is approximately 81.5% of plan

RAYTHEON FORM NO. 4826 (VELLUM)

UNIT OR TASK SCHEDULE

SCHED. CLASSN ______

RESPONSIBLE ENGR ______ UNIT ______ PROJECT ______ D.O. NO. ______



SYMBOLS: ▲——▲ = SCHEDULE LINE ● = ACTUAL START
○——▲ = PERFORMANCE LINE ○ = ESTIMATED START

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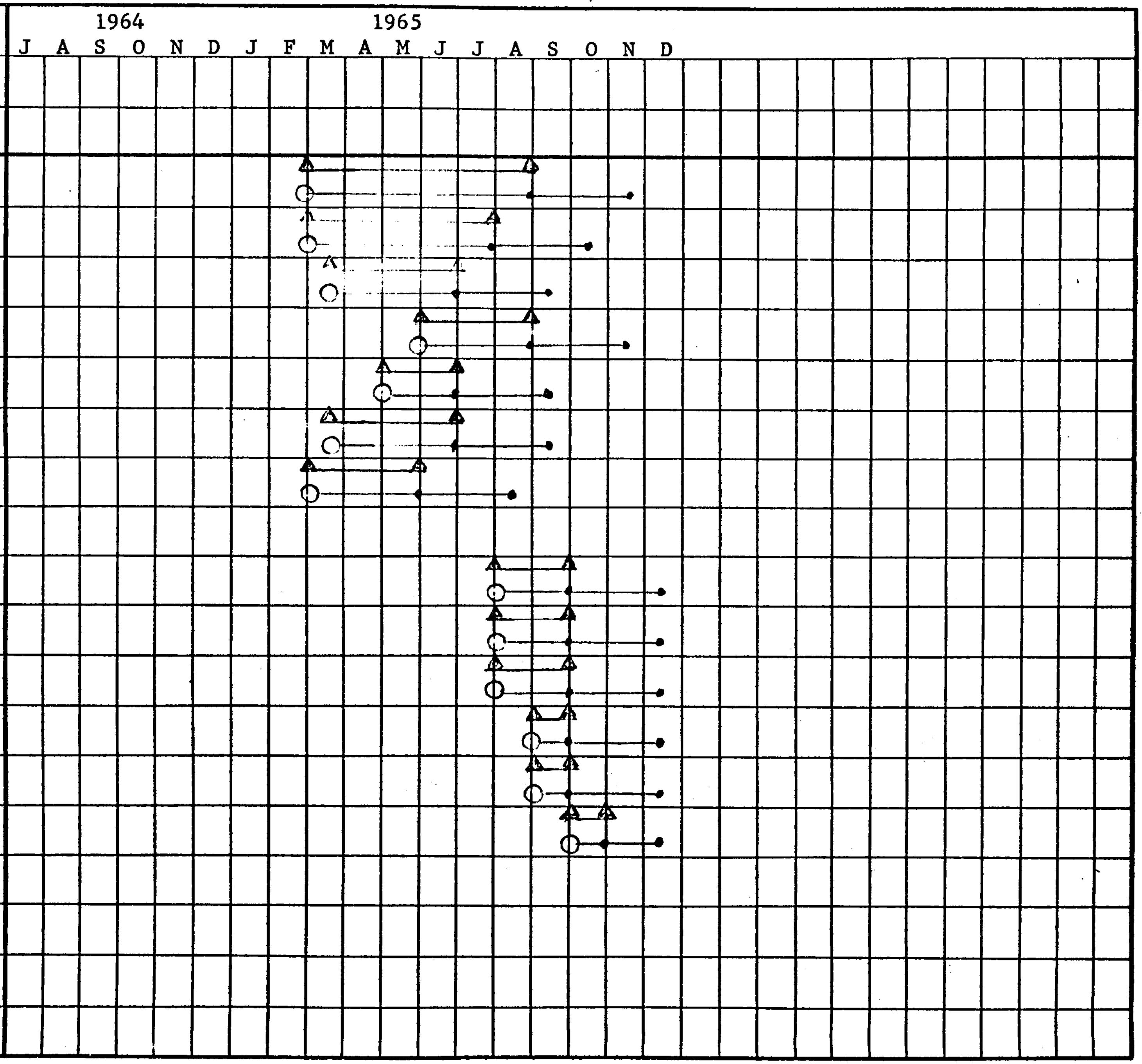
RAYTHEON FORM NO. 4826 (VELLUM)

UNIT OR TASK SCHEDULE

SCHED. CLASSN

RESPONSIBLE ENGR UNIT PROJECT D.O. NO.

ITEM DESCRIPTION	MO/YR PERIOD ENDING REVIEW DATES
PHASE III - REVISIONS	
Test	
Revisions	
Calibration	
Drafting	
Fabrication	
Materials	
PHASE IV - APPLICATION	
Procedures	
Pilot Tests	
Operator Training	
Instruction Book	
Final Report	



SYMBOLS: ▲——▲ = SCHEDULE LINE ○——▲ = PERFORMANCE LINE ● = ACTUAL START ○ = ESTIMATED START

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CONCLUSION

The extra time used in Phase I has given Raytheon a high level of confidence in the proposed design. While it is not now possible to predict areas in which the time may be regained, no further slippages are envisioned. It must be noted that the slippages are not excessive in light of the work that was done during the time used. The preliminary study is the key to success or failure of the whole effort. It was necessary therefore to exhaustively investigate every promising approach. Furthermore it was necessary to confirm these investigations with suitable corroborative calculations. This has been done and has led to several breakthroughs and one file for patent rights on the behalf of NASA. Appendix V invention disclosure. The planned work is within reasonable limits of our capabilities and the instrument design adequately defined and well within the state of the art.

A P P E N D I X I

MATHEMATICAL MODEL
OF SYSTEM

PROBLEM Define a system that can meet certain functional requirements.

These requirements are given in terms of:

1. Target Area Resolution
2. Target Thermal Resolution
3. Target Scanning Rate
4. Data Disposition

APPROACH The first step in the program was to define a function for the system as a whole which would express the relationship between the system elements. The boundary conditions and physical configurations could then be examined and their effect on the system compared.

We begin by constructing a system block diagram arranged so that the elements occur in the order of the energy transfer.

TARGET → OPTICS — SCANNER — DETECTOR — AMPLIFIER → SCOPE RECORDER

Considering that the input to one element is the output of the proceeding one we can consider the elements as "black boxes" having outputs as follows:

1. Target Output $A_T \sigma \epsilon \Delta T^4 = K1$

2. Optics Output $K1 \times \sin^2\theta \; t_t = K2$

3. Scanner Output $K2 \times \frac{E}{\Delta f^{\frac{1}{2}}} = K3$

4. Detector Output $K3 \times \frac{e\mathcal{E}}{NEP} = K4$

5. Amplifier Output $K4 \times G\mathcal{E}_{amp} = K5$

6.a Scope Output (Raster) $K5 \times G\mathcal{E} = I_s/I_n$ (Intensity modulated raster display)

6.b Scope Output (line/point) $K5 \times Gy = \Delta y(\frac{s}{n})$ (Line or point vertical deflection)

6.c Recorder Output (tape) $K5 \times G_R\mathcal{E} = \Delta B(\frac{s}{n})$ (flux density ratio of S/N on tape)

Because the treatment of the system equation beyond the detector element is confined largely to a single regime of electrical signal amplification, we can interrupt the complete function while preserving continuity, by discussing only the first four elements in terms of a detector output (S/N) ratio.

Arranging the foregoing terms in an equation, we have for a general system:

$$1)\quad \left(\frac{S}{N}\right) = As\,\sigma\,\epsilon\,\Delta T^4 \,\sin^2\theta\; t_t\, E\, \Delta f^{-\frac{1}{2}}\; e(NEP)^{-1}\mathcal{E}$$

The terms in this equation include physical constants, contract requirements and system variables, and are grouped in that order below for identification.

A Physical Constants - σ is the Boltzman Constant

ϵ is the surface emissivity (assumed to be 1.0 for targets)

B Contract Specification-As is the area of the instantaneous target.

T is the operating temperature at the target area As

Δf is the bandwidth of the target sampling rate, and is a function of the scanning rate.

C System Variables $\sin^2\theta$ is a function of the solid angle within which the target radiant energy is collected

t_t is the collective transmission coefficient

E is the scanning mechanism efficiency

e is the detector acceptance angle efficiency

NEP is the detector specific NOISE EQUIVALENT POWER

$\mathcal{E}$ is the detector energy conversion factor.

The numerical valves of the group A and B terms are discussed below.

Group A Physical Constants

$\sigma = \frac{cb}{4} = 5.67283 \pm .0037 \times 10^{-12}$ watts $.cm^{-2}$ $.deg^{-4}K$

Where C is the radiation constant defined as

$C = \frac{8\pi^5 k^4}{15C^3 h^2} = 7.56942 \pm .0049 \times 10^{-5}$ $erg.cm^{-3}.deg^{-4}K$

b is the second radiation constant defined as

$b = \frac{hc}{k} = 1.43848 \pm .0034$ cm. deg

ϵ = emissivity; a numeric between 0 and 1.0 and for purposes of discussion here, the targets are assumed to have an emissivity of 1.0.

Group B Contract Requirements

As The system is required to examine three target sizes. The parameters associated with the targets are therefore arranged by column for each target.

	TARGET A	TARGET B	TARGET C
NOMINAL FIELD-	1.0MM X 1.0MM	.25" X .25"(.635cm X .635cm)	1" X 1"(2.54cm X 2.54cm)
TARGET DIA.	1×10^{-3}cm	6.35×10^{-3}cm	2.54×10^{-2}cm
TARGET AREA (A_s)	$7.85397 \times 10^{-7}cm^2$	$3.166919069 \times 10^{-5}cm^2$	$5.06707 \times 10^{-4}cm^2$

I The system is required to have an operating range extending upward from an ambient of 25°C ± 10°C
The thermal resolution required is a 1°C gradient between two target temperatures which for the "worst case" exists with T_1 at 25°C and T_2 at 26°C. The numerical valves as used in the transfer equation are tabulated below.

TARGET 1 T_1	25°C = 298°K	$T_1^4 = 7.87790416 \times 10^9$
TARGET 2 T_2	26°C = 299°K	$T_2^4 = 7.992538801 \times 10^9$
ΔT	1°C	$\Delta T^4 = 1.0638385 \times 10^8 \, °K^4$

Δf Bandwidth $= f_2 - f_1$

The system is required to scan the target fields at a rate extending to 10 fields or frames per second.

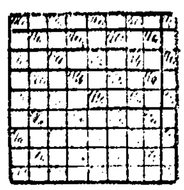
From the discussion of <u>As</u>, the field is composed of targets having diameters equivalent to 1/100 of the nominal field dimension. This gives us in effect a field of 100 lines, with each line containing 100 targets or bits.

f_2 Since we are required to resolve the temperature difference between targets, we can examine a "worst case" condition by allowing alternate targets along each field line to have a temperature T_1, while the remaining targets are assigned a temperature T_2. In scanning therefore, the sensing element will see alternately, P1 and P2, the radiant energy associated with temperature T1 and T2. The cyclic nature of the received energy now becomes function of the scanning speed, with each cycle having a wavelength of two bits.

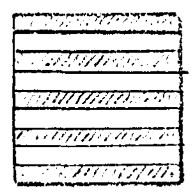
$f_2 = \frac{NF}{2}$ WHERE f_2 is the modulation frequency in cycles per second.
N is the number of bits per frame
F is the number of frames per second.

$$f_2 \quad \frac{10^4 \times 10}{2} = 50\text{KC}$$

FIELD CONFIGURATION FOR f2



FIELD CONFIGURATION FOR f1



f_1 When we consider an extended target, such as might occupy the length of the target field, then the bit size is increased two orders of magnitude so that in substituting in the above equation we have:

$$f_1 = \frac{10^2 \times 10}{2} = 500 \text{ CPS.}$$

The frequency bandwidth over which the detection circuit must operate can now be determined.

$$\Delta f = f_2 - f_1 = 49{,}500 \text{ CPS.}$$

(cont'd.)

<u>$\sin^2 \theta$</u>

For purposes of computing energy transmission, the function $\sin^2\theta$ when multiplied by the radiating source area defines the solid angle within which the energy will be collected by the collecting aperture.

Optically; θ is defined as the angle subtended at the center of the object area by the optical axis and a marginal ray extending to the edge of the aperture.

An equivalent expression for $\sin^2 \theta$ is:

$$\sin^2\theta = \left[1 + 4\, F^2\left(\frac{1}{M} + 1\right)^2\right]^{-1}$$

WHERE F is the F/number of the system and is equal to the focal length f, divided by the aperture diameter D.

M is the system magnification and is equal to the image diameter divided by the object diameter.

<u>t_t</u>

COLLECTIVE TRANSMISSION COEFFICIENT

$$t_t = t_1 \times t_2 \times t_3 \times t_4$$

WHERE:

t_1 is the diffraction loss coefficient
t_2 is the reflection loss coefficient
t_3 is the refraction loss coefficient
t_4 is the obscuration loss coefficient.

t_1

is determined by multiplying the percent of the energy contained in a target image blurr circle J, by the percent of the blurr circle area covered by the detector aperture. (for a diffraction limited system)

let $t_1 = \frac{J \times Ad}{ABC}$

at the diffraction limit, $J \cong .85$ so that

$t_1 = \frac{.85\, Ad}{ABC}$

The optimum condition for t_1 exists when the area of the detector aperture equals exactly the area of the blurr circle in which case, $t_1 = .85$

t_2

reflection loss coefficient

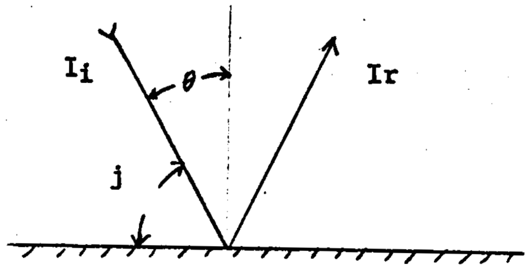
For any optical system, a portion of the transmitted energy is lost at each surface that lies in the optical path. The loss sustained is proportioned to surface reflectivity and is determined by the surface condition for otherwise opaque materials.

It is customary to specify the reflectivity for a given material as the percent of energy K reflected when the direction of incident energy is normal to the plane of the reflecting surface, so that all values of t_2 are between K for an incident angle j, of 90° and approaches 0 as the incident angle approaches 0°.

If I_i is the energy incident on a reflecting surface at an angle θ with respect to the normal, the reflected energy Er can be determined from:

$$\frac{I_i}{I_i} = K \cos \theta$$

The ratio of Er/Ei is the coefficient t2.



t_3 Refraction loss coefficient

As with the reflection coefficient, all radiant energy incident on a surface is distributed in three modes. It may be reflected, absorbed, or transmitted. In practice, all three modes are involved, particularly with those materials not opaque to the wavelength of the radiation of interest.

If I_j is the quantity of incident energy, then:

$$I_j = I_r + I_a + I_t$$

WHERE I_r is the quantity of reflected energy
I_a is the quantity of energy absorbed

I_t is the quantity of energy transmitted

For refractive elements, such as the window for the evacuated detector dewar, or corrective lenses, we are primarily interested in the energy transmitted thru the refractive medium so that

$$I_t = I_j - I_a - 2I_r$$

(The reflection coefficient of 2 is required because there will be two surfaces for an element, each of which reflects a portion of the incident radiation.)

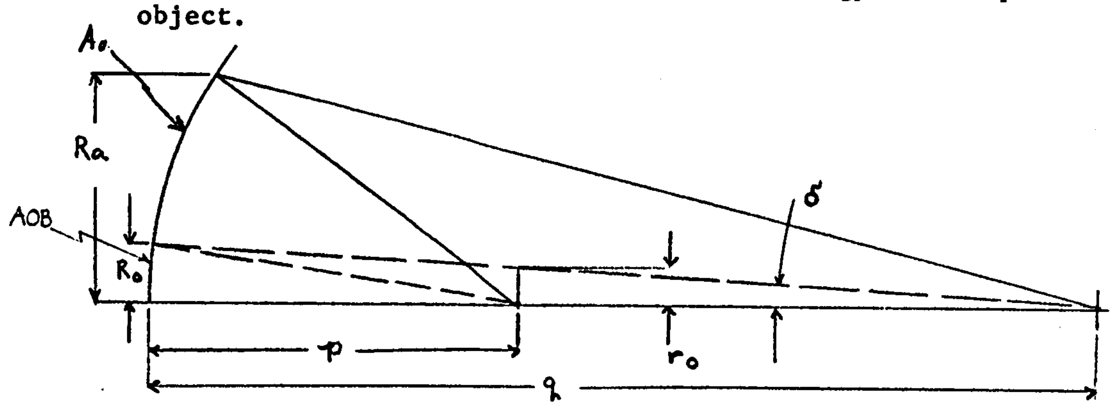
Table below lists some materials that are frequently used as refracting or optical elements in the infrared region of radiation. They are listed together with their corresponding "t_3" and reflection coefficient "t_2".

MATERIAL	T_3 (λ)(μ)		T_2 (λ) (μ)	
Potassium Chloride	.932	10	.068	10
Potassium Iodide	.95	10	.106	12
Sodium Chloride	.925	12.5	.075	10
Barium Fluoride	.923	8	.077	
Potassium Bromide	.916	10	.084	10
Cesium Iodide	.9	to 40	.136	10
Silver Chloride	.8	to 18	.195	10
Cesium Bromide	.884	to 26	.116	10
Thallium Chloride	.782	10	.218	10
KRS-5	.726	to 30	.284	10

For succeeding arguments in this study, we will use the value for t_3 corresponding to Potassium Chloride: or .932. The total numerical value will then be $t_3 = .932^N$ where N is the number of refractive elements in the system.

t_4- OBSCURATION COEFFICIENT

The obscuration coefficient t4, does not appear in the transfer equation for either a difffractive or refractive system. It does however appear for those reflective systems in which the incident and reflected optical axes are coincident. The obscuration is due to the blocking effect of the reflected energy of the plane of the object.



One method of expressing t4, is to express it as a ratio of the objective aperture area Aa to the projected area of the obscuration circle A_{OB}.

$$t_4 = \frac{A_{OB}}{Aa}$$

The obscuration area $A_{OB} = \pi Ro^2$, where $Ro = q \text{ Tan } \delta$ and $\text{Tan } \delta = \frac{ro}{q-p}$. . ro is the radius of the obstructing element.

Other equivalent expressions for t_4 are:

$$t_4 = \frac{\pi Ro^2}{\pi Ra^2} = \frac{Ro^2}{Ra^2} = \frac{q^2 \text{ Tan}^2 \delta}{Ra^2} = \frac{ro^2/(q-p)^2}{Ra^2} = \frac{ro^2}{Ra^2 (q-p)^2}$$

$$= \frac{\sin^2 \delta}{Ra^2}$$ or, since $q = Mp$; $t_4 \quad \frac{ro^2}{Ra^2 [(M-1)p]^2}$

E SCANNING MECHANISM EFFICIENCY

The scanning mechanism efficiency can be expressed in either of two forms, i.e., time or bits.

In terms of time, the efficiency is the ratio of the total elapsed time from the beginning of one frame to the beginning of the next, to the actual time on the target field.

$E = \frac{t_f}{t_t}$ where t_f is the actual time on the field
f_t is the total elapsed time from the beginning of frame a) to the beginning of frame b).

In terms of bits; the efficiency is the ratio of the total number of bits from frame to frame, to the number of bits in one frame.

$E = \frac{Nf}{Nt}$ where Nf is the exact number of bits in one frame
Nt is the total number of bits from frame to frame.

e Detector Aperture Efficiency-

The detector aperture, as with any aperture in an optical system can be described by a function that expresses the field of view, the acceptance angle and the aperture diameter.

As we said earlier, the diameter for the detector is optimun when its area Ad, corresponds exactly to the blurr circle area of the optical system.

It becomes apparent also that the acceptance angle becomes optimum when it agrees with the optical convergence angle θ^1, so that the optical aperture completely fills the field of view of the detector aperture. ERGO; for a given system:

$$Ad = BCA$$

$\sin^2 \phi = \sin^2 \theta^1$ where ϕ is defined as the half/angle of acceptance for the detector.

If the optical system is adjusted to focus a target of different size but maintaining the image field constant, then the convergence angle will change.

If the new convergence angle θ'' is smaller than θ^1, the detector will see a field larger than the optical aperture and conversely; if θ'' is larger thru θ^1, the optical aperture will be effectively stopped down: reducing the quantity of energy from the target that is received by the detector.

The coefficient e, then can be expressed as the ratio of the $\sin^2$ function or:

$$e = \frac{\sin^2 \theta^1}{\sin^2 \phi}$$ (assuming the BCA remains constant)

In the discussion of various optical systems, it will be seen that the above assumption does not hold for certain configurations. The effect of varying BCA will be discussed in more detail as the various optical configurations are presented, in which case :

$$e = Ad \sin^2 \phi$$

WHERE: Ad is the detector aperture area and $2\,\phi$ is the acceptance angle.

$\mathcal{E}$ = Detector energy conversion factor.

The detector conversion factor is usually expressed as the detector responsivity which is defined as:

$$R = \frac{V_s}{P_t\, Ad}$$

WHERE: R is the detector responsivity in volts per watt.

P_t is the RMS power flux density of the radiant energy incident on the detector in watts/cm^2

Ad is the area of the detector aperture

V_s is the RMS detector output signal voltage given as:

$$V_s = \frac{E(R_L\, R_C)}{(R_L + R_C)^2} \quad \frac{G\tau}{N}$$

E is the detector bias supply voltage

R_L is the load impedance

R_C is the detector impedance

τ is the detector time constant

N is the number of carriers excited thermally (N_t) and by background (N_b)

G is the carrier generation rate, given as:

$$G = \alpha\, J_s\, (\chi)$$

α is the detector element absorption coefficient;

$= \sigma N_t$

σ is the cross section of the impurity level (cm^2)

N_t is the density of the impurity level in atoms per CM^3

$J_s(\chi)$ is the number of photons absorbed per unit area, per unit time and is related to the total number of incident photons by: $J_s(\chi) = J_s(o)\, e^{-\alpha\chi}$

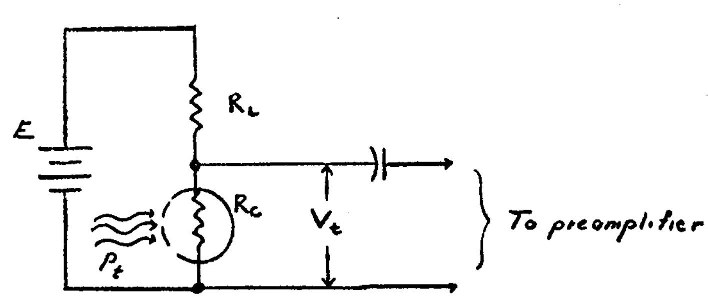
χ is the thickness of the detector element.

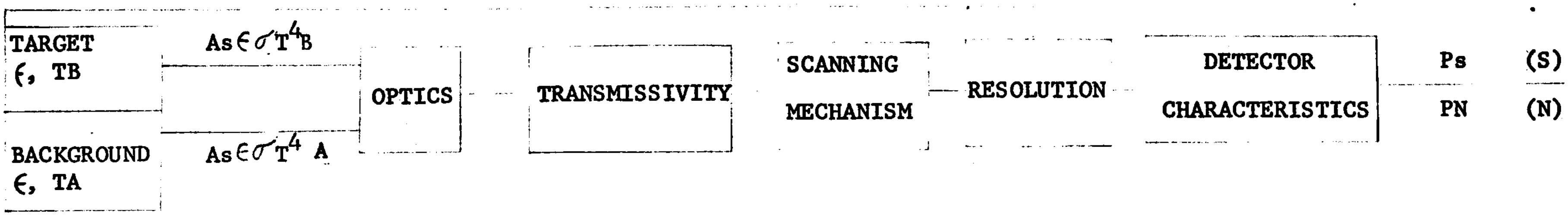
NEP Detector Noise Equivalent Power.

The detector NEP is defined as the RMS value of the sinusoidally modulated radiant power which will cause an RMS signal voltage to equal the RMS noise voltage of the detector

$$NEP = \frac{P_T \quad A}{\left(\frac{VS}{VN}\right)(\Delta f)^{\frac{1}{2}}} \quad \text{WATTS/CPS}^{\frac{1}{2}}$$

WHERE
- P_T is the RMS power flux density in watts/cm^2
- A is the area of the detector aperture in cm^2
- Vs is RMS signal voltage
- Vn is RMS noise voltage
- Δf is the bandwidth of the measuring conditions in CPS.





$\frac{As}{\epsilon \sigma T^4}$ | $\sin^2\theta$ | t_t | $E/\Delta f^{\frac{1}{2}}$ | eM^2As | NEP(1CPS)

TRANSFER FRACTION:

$$\frac{S}{N} = \frac{As \sin^2 \theta \, t_t \; Ee \; (T_B{}^4 - T_A{}^4)}{\underset{(1\ CPS)}{NEP} \; \Delta f^{\frac{1}{2}}}$$

WHERE:

- As = Area of the radiation source (cm^2)
- ϵ = Source emissivity
- σ = Stephen - Boltzman constant (5.6686×10^{-12} WATTS/cm^2/deg K^4)
- TB = Temperature of $target_B$ (°K)
- TA = Temperature of surrounding background (assumed to be ambient)
- $As \sin^2 \theta$ = Solid angle within which the radiant energy is collected
- t_t = Transmissivity coefficient; due to various transmission losses
- E = Efficiency of the scanning mechanism (Total bits/sec ÷ target bits/sec)
- f = Frequency of the target sampling rate (Total bits/sec 2)
- e = Detector aperture efficiency (fixed area As and angle θ
- M = Magnification
- NEP = Detector NOISE Equivalent Power (WATTS/CPS $^{\frac{1}{2}}$)

$$\left(\frac{S}{N}\right) = \sigma \epsilon \frac{(T_B{}^4 - T_A{}^4)}{NEP \; \Delta_f{}^{1/2}} \times As \sin^2\theta \; t_t \; E \; e$$

$\left(\frac{S}{N}\right)$ = System Independent Parameters X System dependent variables = K_1 & K_2

A P P E N D I X II

DETECTOR STUDY

A COMPARATIVE EVALUATION OF COPPER ACTIVATED GERMANIUM AND MERCURY ACTIVATED GERMANIUM INFRARED DETECTORS

Introduction

The purpose of this program is to compare the performance characteristics of copper activated germanium (Cu:Ge) and mercury activated germanium (Hg:Ge) photoconductive infrared detectors.

The performance factors of the detectors and the fundamental parameters which determine detector performance are described.

Discussion

General

The most common performance factors used to describe the sensitivity of infrared detectors are noise equivalent power, detectivity and responsivity. Appendix I defines these performance factors.

These performance factors are qualified by specifying test conditions. The standards of the infrared industry being a 500° Kelvin target, a 900 cps chopper and a bandwidth normalized to a one cps. (e.g., NEP (500, 900, 1).)

Detector Cooling

In order to achieve peak performance from photoconductive infrared detectors they must be operated background limited. An infrared photoconductive detector is said to be background limited when the electrical conductivity of the detector is determined only by photons incident on the detector; this is achieved by making the thermal ionization negligible by cooling the detector. This is illustrated in Figure 1 which is a graph of thermal and background noise versus temperature for Au:Ge, Hg:Ge and Cu:Ge detectors. Referring to Figure 1, the Hg:Ge detector is background limited below approximately 35°K; above that temperature it would continue to operate but with decreased sensitivity.

Cu:Ge operates background limited below approximately 15°K. In order to achieve this operating temperature some cryogenic method must be used. This requires mounting the detector in a cryogenic dewar. A convenient way of obtaining temperatures in that range is by the use of liquid helium; liquid hydrogen also can be used at reduced pressures when the explosiveness of hydrogen is of no concern.

Hg:Ge operates background limited below 35°K. Hg:Ge can be cooled by cryogenic liquids (i.e., helium, hydrogen or neon) by the same techniques as Cu:Ge. However, several closed cycle refrigerators which can sufficiently cool Hg:Ge are commercially available. Operation with the cryogenic refrigerator eliminates the logistics problems associated with cryogenic liquids and requires only electric power.

Detectivity

In order to optimize sensitivity we must reduce to a minimum the number of photons arriving from the background. This could be accomplished by cooling the background. Figure 2 shows the variation of peak detectivity (D*) for 3, 6, and 15 microns detectors as a function of background temperature. However since cooling the background within the field of view is not possible, the radiation emitted from the background must be reduced by use of cooled band pass filters which attenuate background radiation greatly and let the signal radiation pass. Figure 3 is a spectral response curve of filtered and unfiltered Hg:Ge germanium and Cu:Ge germanium.

As a result of the aforementioned background considerations the detectivity (D*) is also a function of the acceptance angle (θ). The acceptance angle is defined as the total solid angle of radiation that can be incident on the detector.

$$\frac{D^*(\theta)}{D^*(180^\circ)} = \frac{1}{\sin\frac{\theta}{2}}$$

Figure 4 is a graph illustrating the effect of the acceptance angle of detectivity. It has been observed that detectivity increases also with decreasing aperture size. Figures 5 and 6 illustrate experimental measurements made with copper activated germanium and mercury activated germanium detectors. In theory, the detectivity should be independent of the aperture area; the observed variation is most probably due to the fact that the acceptance angle is not equally well defined for all areas.

The detectivities of Hg:Ge and Cu:Ge are equally high. Both detectors, when background limited, increase in detectivity with decreasing background radiation and are most sensitive for small area apertures.

Responsivity

The responsivity of mercury doped germanium and copper doped germanium are essentially equal. It has been found experimentally that the responsivity increases with decreasing aperture area. Figure 7 illustrates the responsivity as a function of aperture area. The above makes both Hg:Ge and Cu:Ge detectors well suited to high resolution systems.

Impedance

The impedance is another parameter which must be considered since high resistance detectors may exhibit a RC time constant which is considerably longer than the intrinsic detector response. This results in reduced frequency response (e.g., $C = 6.0 \times 10^{-12}$ farads, $R = 2.0 \times 10^{5}$ ohms, and $\tau = 6.0 \times 10^{-12} \times 2.0 \times 10^{5} = 1.8 \times 10^{-6}$ seconds).

The impedance of photoconductive infrared detectors is dependent on material resistivity, contacts, operating temperature, detector geometry and background radiation. The dependence of detector impedance on background radiation is shown in Figure 8, in which repeated measurements were made on Hg:Ge and Cu:Ge detectors with various apertures on the detectors. While recent work (i.e., on material resistivity and on geometry) has considerably reduced the magnitude of the impedances shown, it is clear that impedance must be a major consideration in selecting aperture size.

In addition to background radiation proper detector geometry and encapsulation can substantially reduce the impedance of the detector.

Both Cu:Ge and Hg:Ge have approximately the same resistivity at their operating temperatures and are affected similarly by background radiation. However, we must also consider dynamic impedance. Neither Cu:Ge nor Ge:Hg exhibit ohmic behavior. When high bias voltages are applied to Cu:Ge the dynamic impedance is substantially reduced. Figure 9 is a curve of dynamic impedance versus bias voltage for a typical Cu:Ge detector.

In the case of Hg:Ge, the dynamic resistance initially decreases with increasing voltage and as higher bias voltages are applied the dynamic impedance passes through a point of inflection and increases. At the optimum bias voltage the dynamic impedance is reduced to approximately 60% of the static impedance. This is illustrated in Figure 9.

From the standpoint of dynamic impedance Cu:Ge is the best choice.

Time Constant

The response time of both the Cu:Ge and Hg:Ge infrared detectors is less than 1 microsecond. The practical limitation is the RC time constant of the detector, dewar and preamplifier combination. From this standpoint the Cu:Ge detector, due to its lower dynamic impedance is best suited. A judicious choice in aperture size must be made in order that the dynamic detector impedance is not too high.

Spectral Response

The targets which will be considered of interest are between 300°K and 700°K. The peak blackbody emittance for these temperatures occur at wavelengths of 9.7 microns and 4.1 microns respectively. Figure 10 illustrates the distribution of radiant emittance for several temperatures. The region of interest for the range 700°K to 300°K is 2 to 14 microns. The spectral response of either Hg:Ge or filtered Cu:Ge (i.e., a cooled 14 micron filter) best match this region. Figure 3 illustrates the spectral response of Cu:Ge and Hg:Ge with various filters.

If only temperatures below 400°K were to be considered than Cu:Ge with a cooled 8-14 micron filter would be the best choice.

Summary

The figures of merit of infrared detectors have been defined. The parameters which determine detector sensitivity have been discussed in relation to both Cu:Ge and Hg:Ge detectors. The criterion which determine the choice of Hg:Ge or Cu:Ge for viewing targets in the range from 300°K to 700°K have been evaluated. The criterion which have been considered are:

1. Detectivity
2. Responsivity
3. Response time
4. Spectral Response
5. Impedance
6. Operating temperature

The use of infrared transmitting fibres has been considered and appears feasible after the solution of the practical problems. (Appendix III)

The detectivity, responsivity and response time of Cu:Ge and Hg:Ge are comparable. For the targets of interest the spectral response of Hg:Ge and filtered Cu:Ge (i.e., a cooled 14 micron filter) are comparable. If only targets in the range of 300°K - 400°K are considered, Cu:Ge with a cooled 8-14 micron filter would be superior.

Since the dynamic impedance of Cu:Ge decreases with increasing bias voltage, Cu:Ge is the best choice where high frequency response is required. The lower impedance of Cu:Ge simplifies the problem of minimizing the RC time constant.

The availability of closed cycle refrigerators to cool Hg:Ge is an extremely attractive feature. This eliminates the logistics problems encountered in handling cryogenic fluids and permits operation with electric power.

In conclusion, if an aperture area and acceptance angle are chosen which will result in a low impedance, Hg:Ge is best suited to the application. However, if the RC time constant of the detector, dewar and preamplifier combination will limit the system Cu:Ge with a 14 micron cut off filter should be used.

Appendix I Performance Factors

a) Noise Equivalent Power (NEP)

The noise equivalent power of a detector is defined as the RMS value of sinusoidally modulated radiant power which will cause a signal to noise ratio of one for a one cycle bandwidth.

$$NEP = \frac{H_T A}{S/N\ (\Delta f)^{1/2}} \qquad \frac{\text{watts}}{\text{cps}^{1/2}}$$

where H_T = rms value of power flux density incident on the detector in watts/cm^2

A = area of the detector in cm^2

Δf = bandwidth of the electronics in cps

S/N = signal to noise ratio

Appendix II illustrates a typical set of test data taken at our laboratory.

b) Detectivity (D*)

Detectivity is the performance figure which normalizes sensitivity to a unit area.

$$D^* = \frac{A}{NEP}$$

c) Responsivity

The responsivity is the RMS signal voltage per unit RMS radiant power incident on the detector.

$$R = \frac{S}{H_T A} \qquad \frac{\text{volts}}{\text{watt}}$$

where S = rms signal voltage in volts.

Appendix II

Noise Equivalent Power (NEP) measurements are made in our laboratory as follows:

A 500°K blackbody with an area of .33 cm^2 is used as the target. The detector is placed 71 centimeters from the target. Sinusoidal modulation is obtained by interupting the signal with a slotted blade (i.e., chopper) designed to permit modulation at 900 cps. The RMS power density at the detector is then calculated to be 2.3×10^{-6} watts/cm^2.

The rms power density is calculated from the following:

The power radiated by a blackbody is given by the Stefan Boltzmann law as:

$$A_{BB} \ \sigma \ (T^4 - T_o^4)$$

where A_{BB} = target area (blackbody)

σ = Boltzmann constant

T = target temperature

T_o = background temperature

The power density per unit solid angle at the detector at a distance D from the blackbody is

$$\frac{1}{\pi D^2} \qquad A_{BB} \ \sigma \ (T^4 - T_o^4)$$

and the route mean square value obtained by dividing by $2 \sqrt{2}$.

A typical set of test data is as follows:

Detector aperture diameter = .012 inches = 3.0×10^{-2} cm

aperture area = 7.3×10^{-4} cm^2

total acceptance angle (θ) = 45°

signal = 440 microvolts

noise = 10.8 microvolts

Δf = 112 cps

$$\text{NEP } (500,\ 900,\ 1) = \frac{2.3 \times 10^{-6} \text{ watts/cm}^2 \ \ 7.3 \times 10^{-4} \text{ cm}^2}{440\ \mu v/10.8\ \mu v \ \ (112 \text{ cps})^{1/2}} = 3.9 \times 10^{-12} \text{ watts/cps}^{1/2}$$

$$D^* (500,\ 900,\ 1) = (7.3 \times 10^{-4} \text{ cm}^2)^{1/2}/3.9 \times 10^{-12} \text{ watts/cps}^{1/2} = 6.8 \times 10^9 \text{ cm cps}^{1/2}/\text{watt}$$

Appendix III

Fibre Optics

It has been reported that infrared transmitting fibres can be made with a calculated transmission of 55% in the 2-12 micron region. A transmission curve for the fibres was supplied by Optics Technology, Inc.

The following are theoretical results which would be obtained if the detector and fibre were used in the following manner.

1. The one end of the fibre is used as the outer window and the other end placed over a small detector aperture.

2. The fibre is cooled to some intermediate temperature (e.g., $150^{\circ}K$). Essentially the detector sees nothing but a $150^{\circ}K$ background. Referring to Figure 2, this would increase peak detectivity by a factor of 10. However, we must consider detector impedance.

$$R \sim \frac{1}{N_B}$$

where R = detector resistance

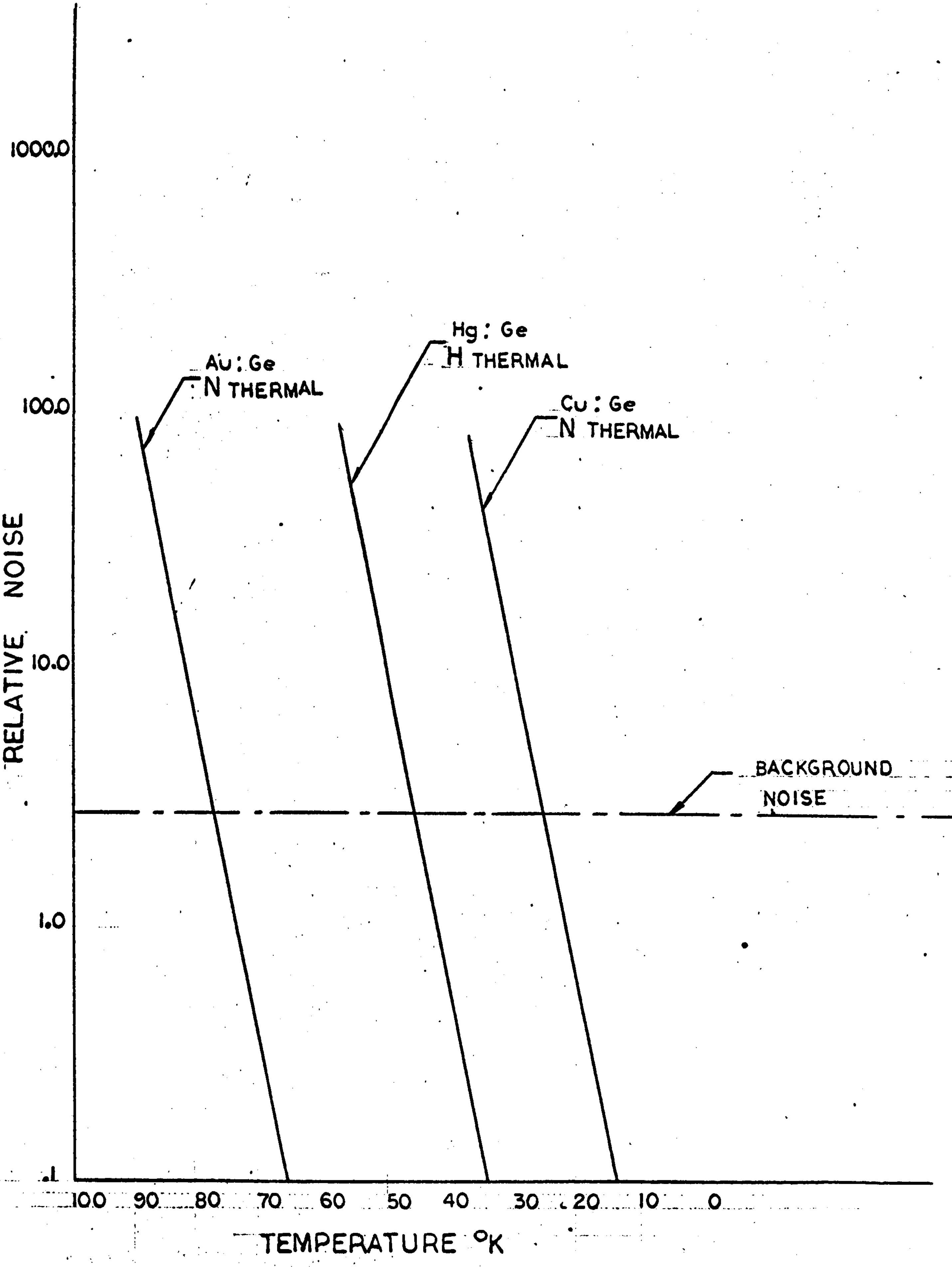
N_B = background generated carriers

Reducing the background temperature from $300^{\circ}K$ to $150^{\circ}K$ would reduce background irradiance by a factor of 100. This would increase resistance by a factor of 100.

Since the device utilizes a small aperture area detector, it was a high impedance device before the background was reduced.

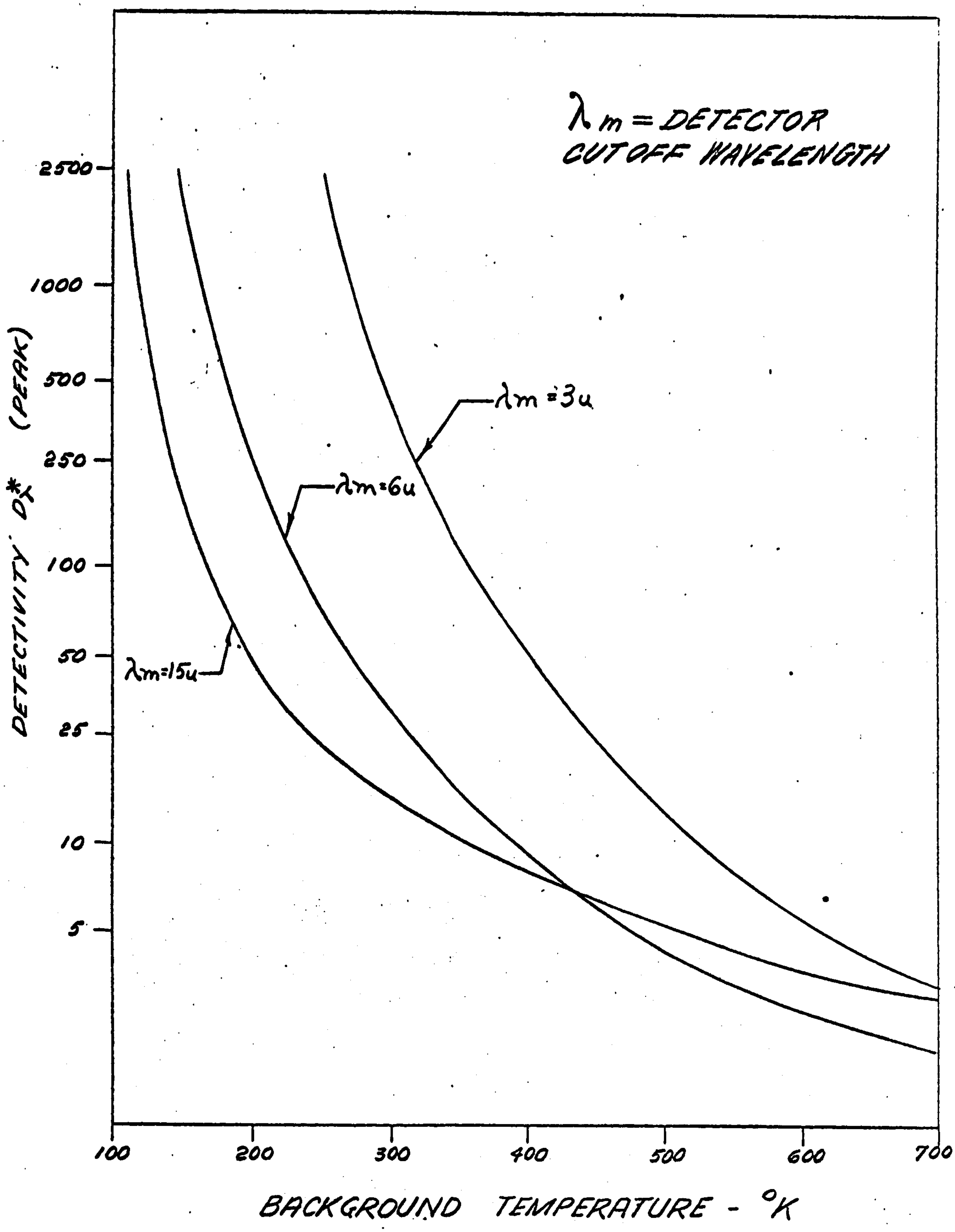
The above brief exercise points out that compromises would have to be made if such a fibre were used. It must also be pointed out that practical problems have not been considered. Some of the first practical problems that would require solutions are:

1. Heat conducted through the fibre to the detector
2. Cooling the fibre
3. Holding the fibre in position
4. Handling the fragile fibre



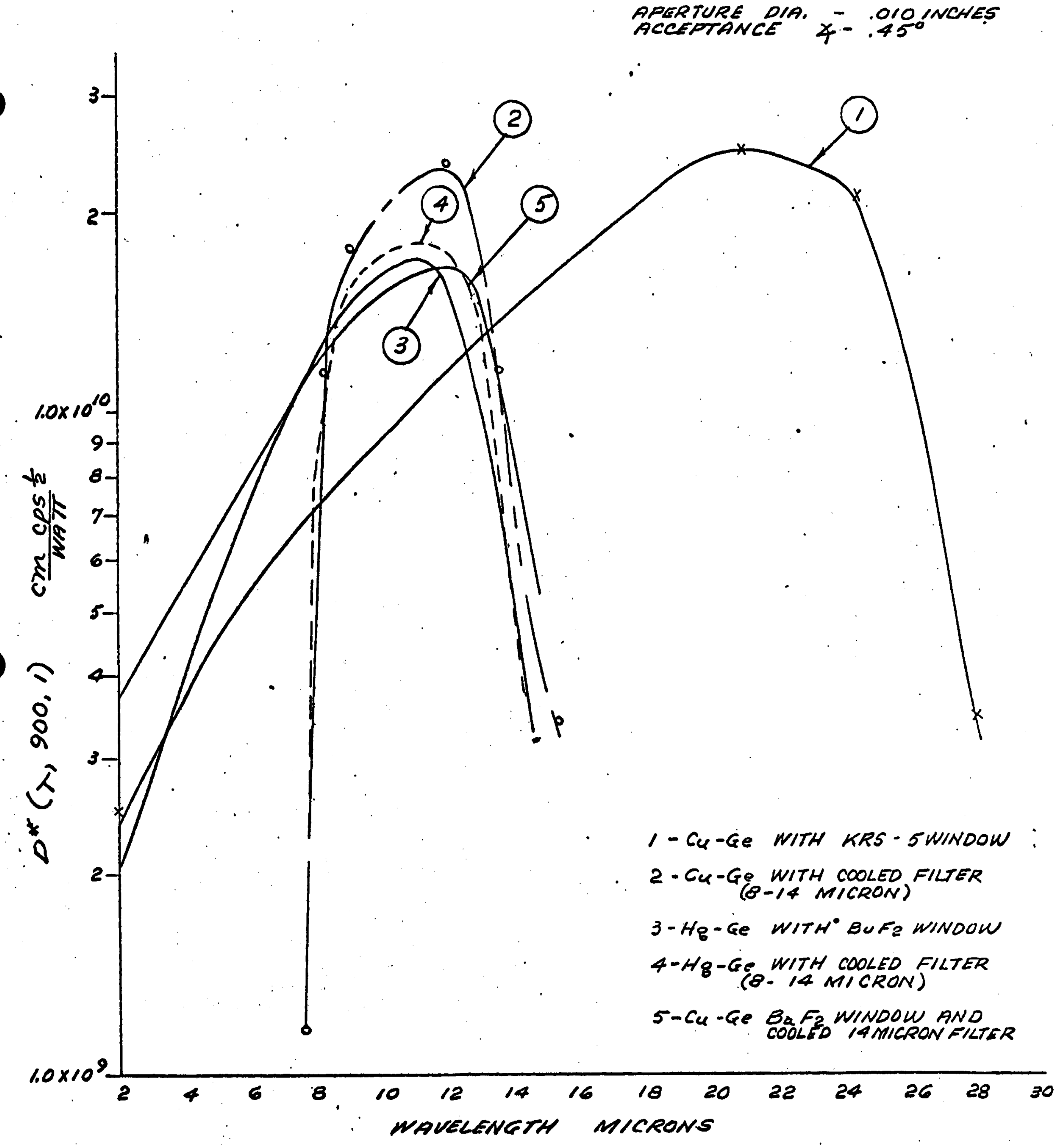
NOISE vs TEMPERATURE

FIG. 1



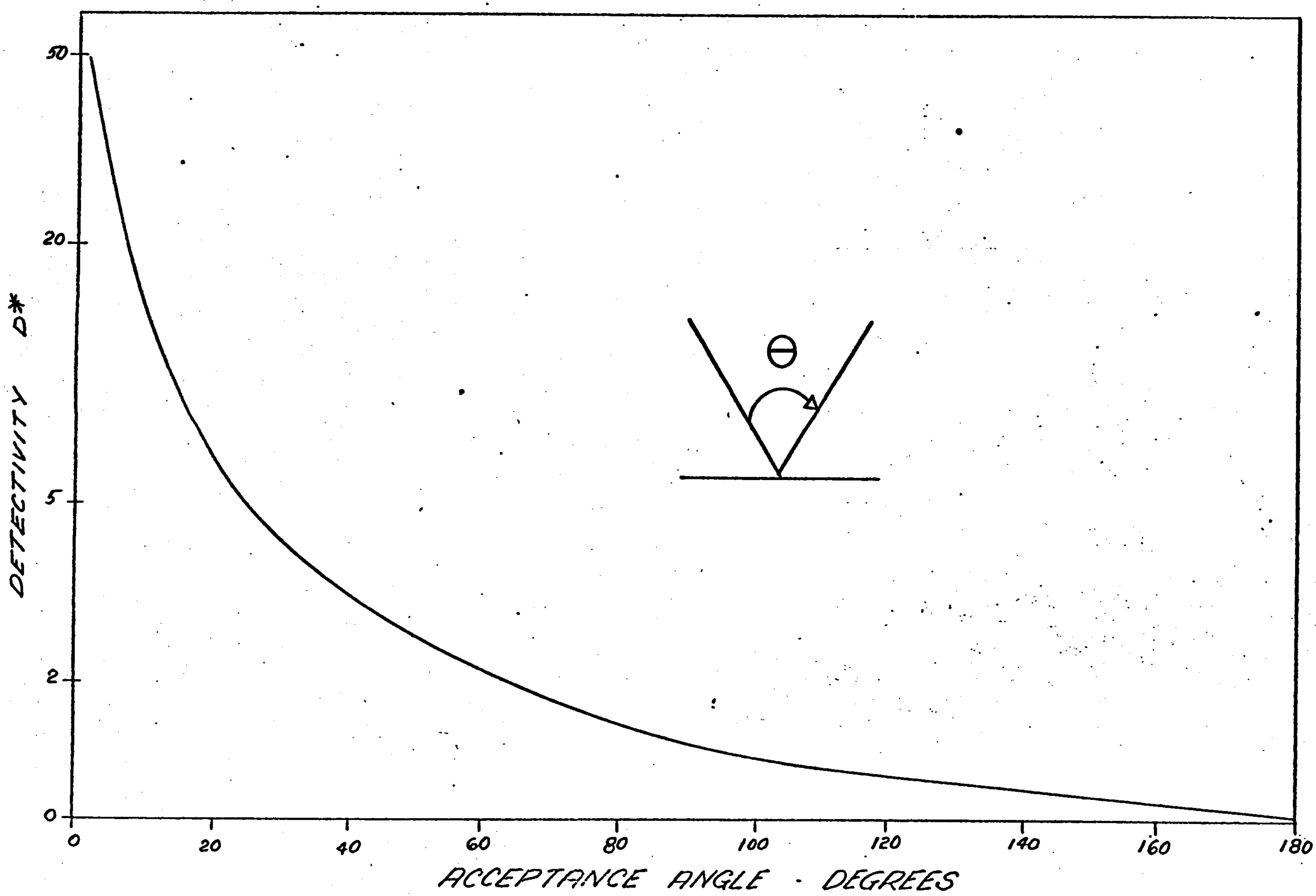
DETECTIVITY vs BACKGROUND TEMPERATURE

FIG. 2



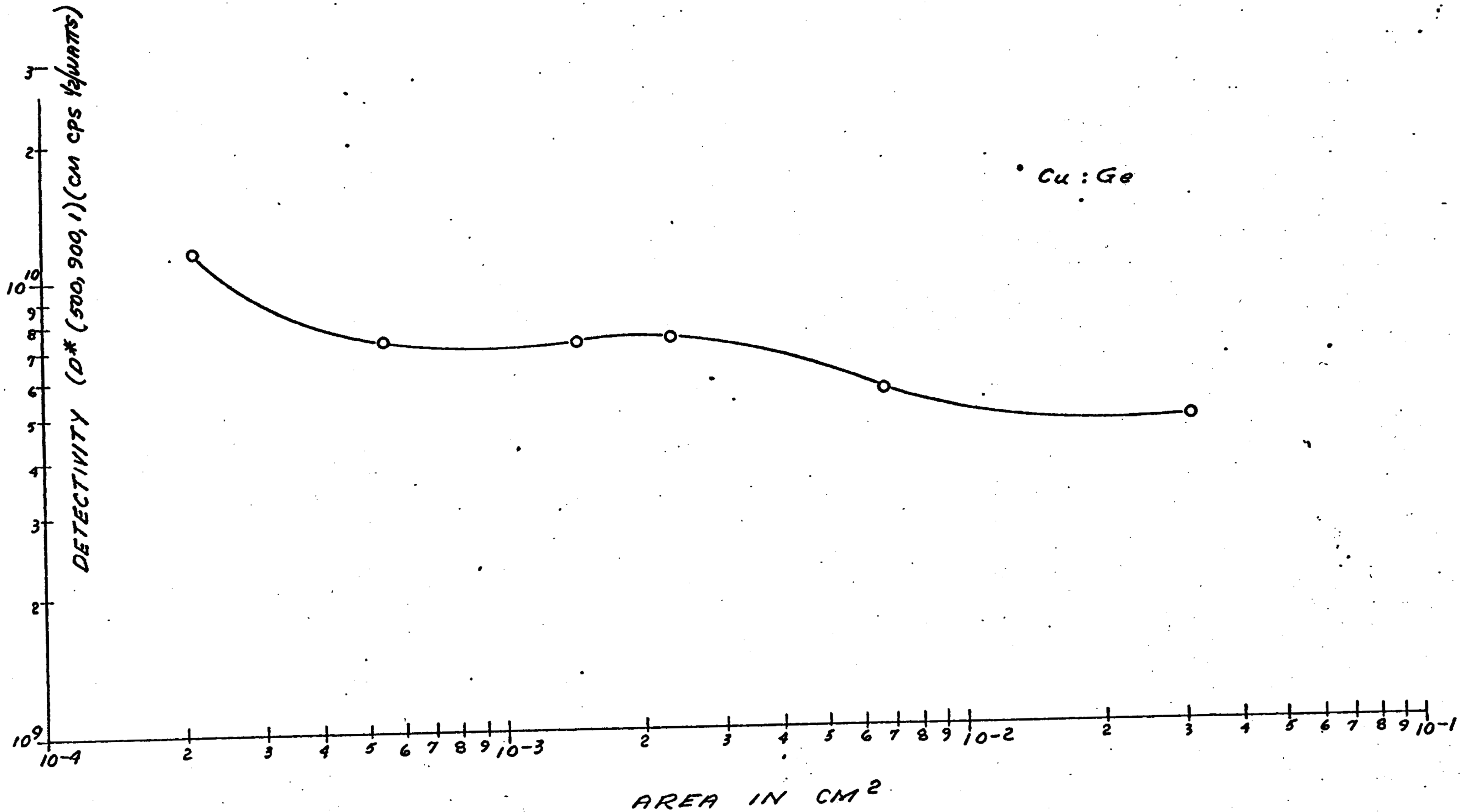
SPECTRAL RESPONSE

FIG. 3



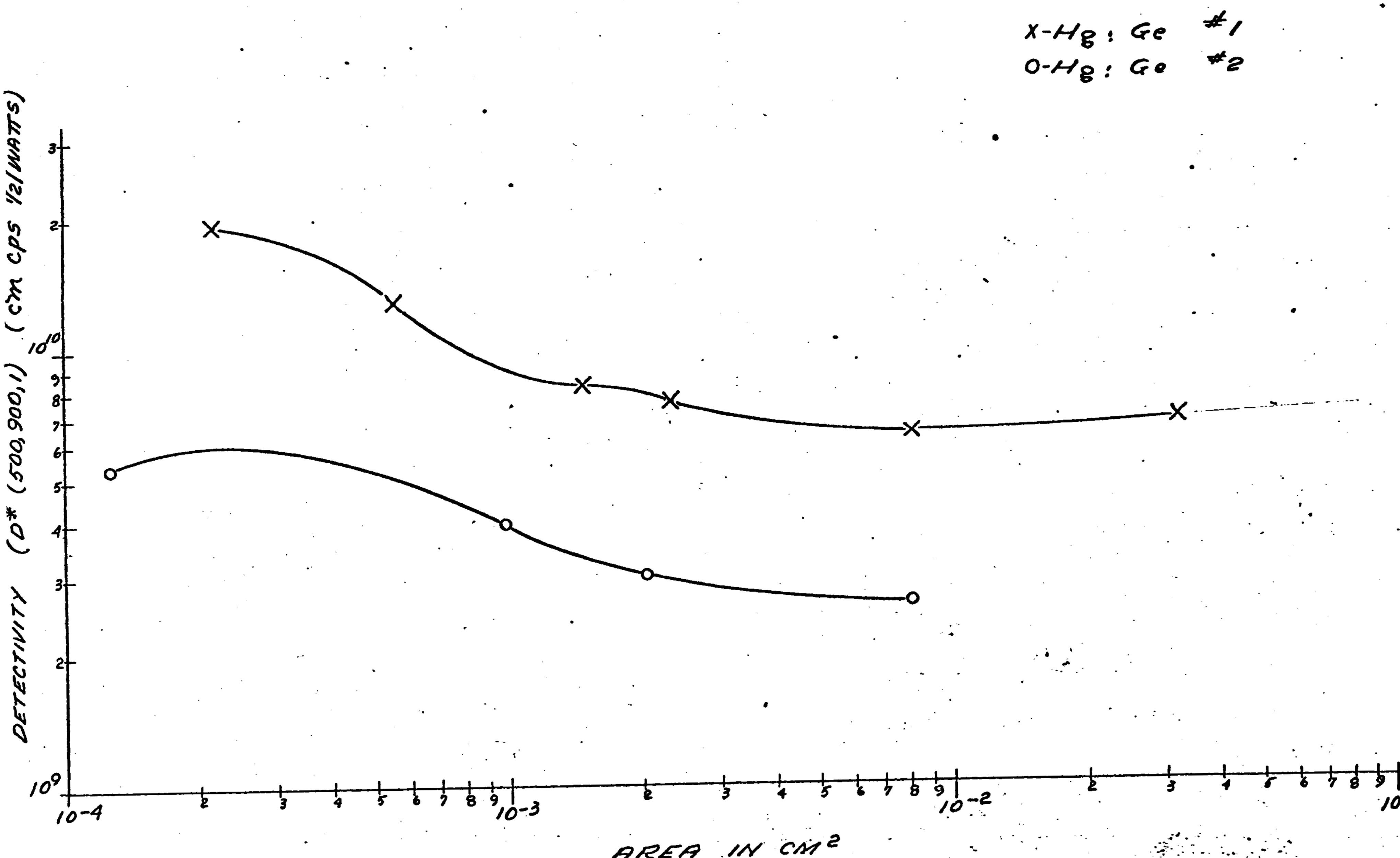
DETECTIVITY vs ACCEPTANCE ANGLE

FIG. 4



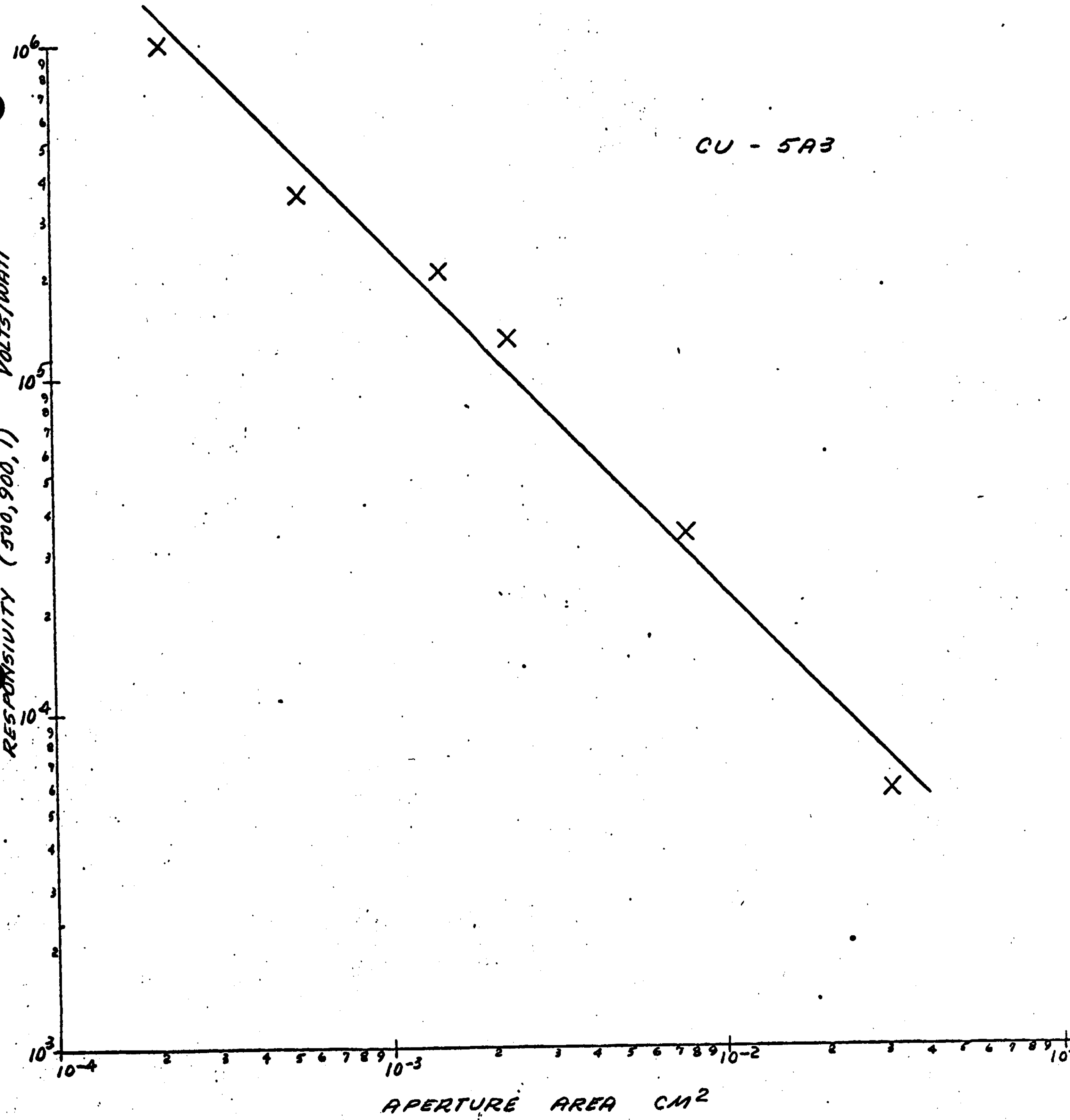
DETECTIVITY vs AREA

FIG. 5



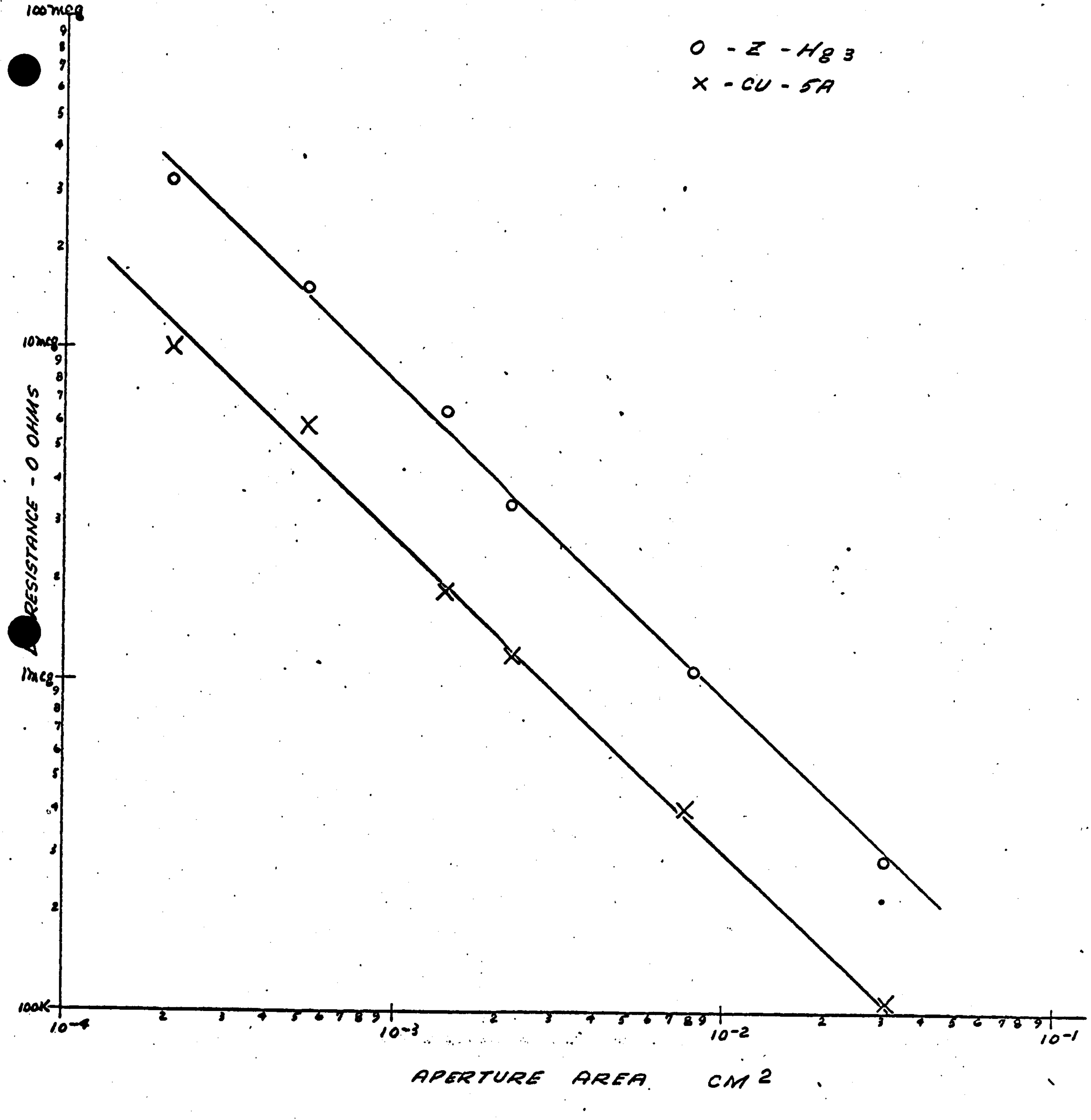
DETECTIVITY vs AREA

FIG. 6



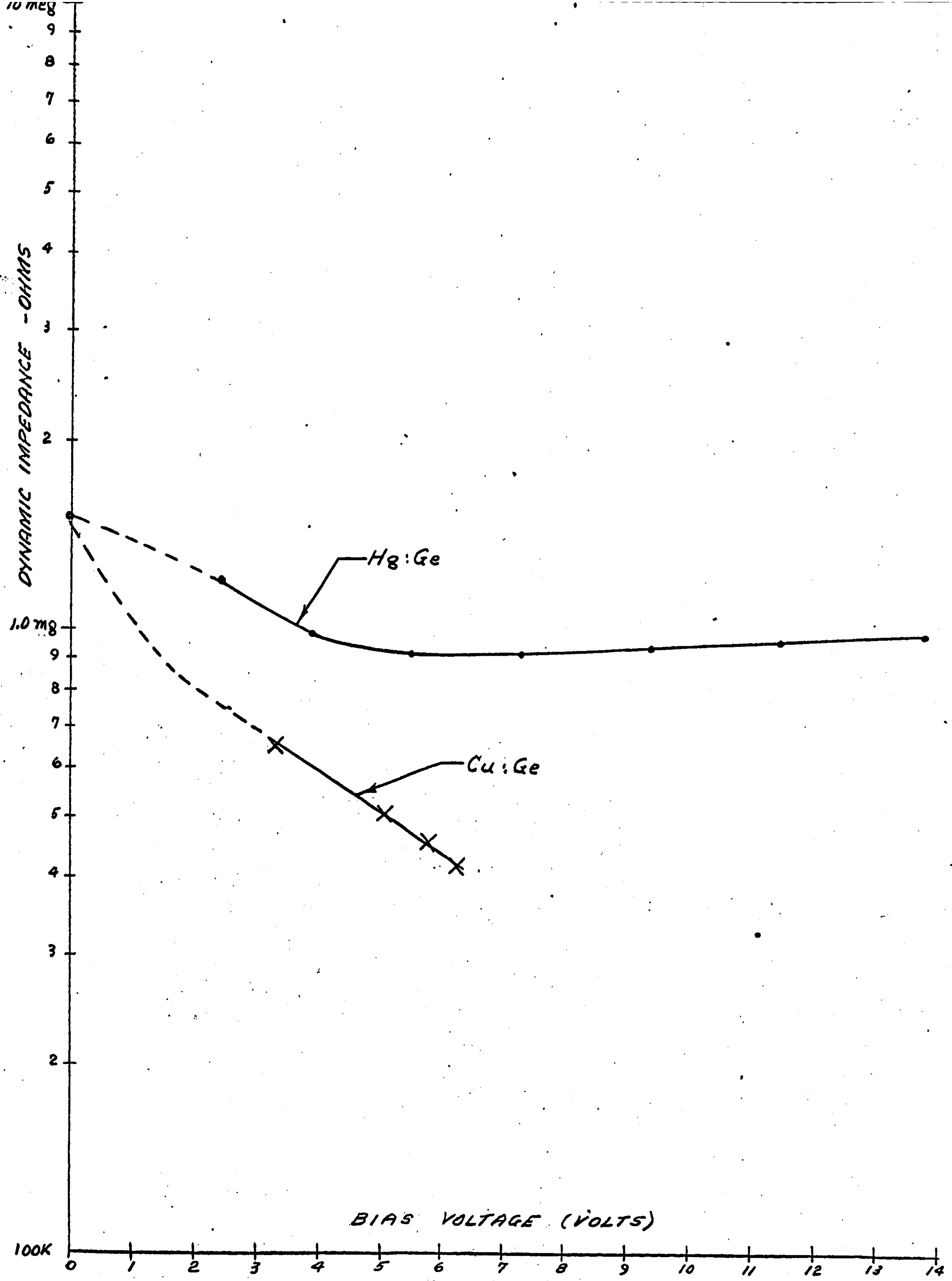
RESPONSIVITY vs APERTURE AREA

FIG. 7



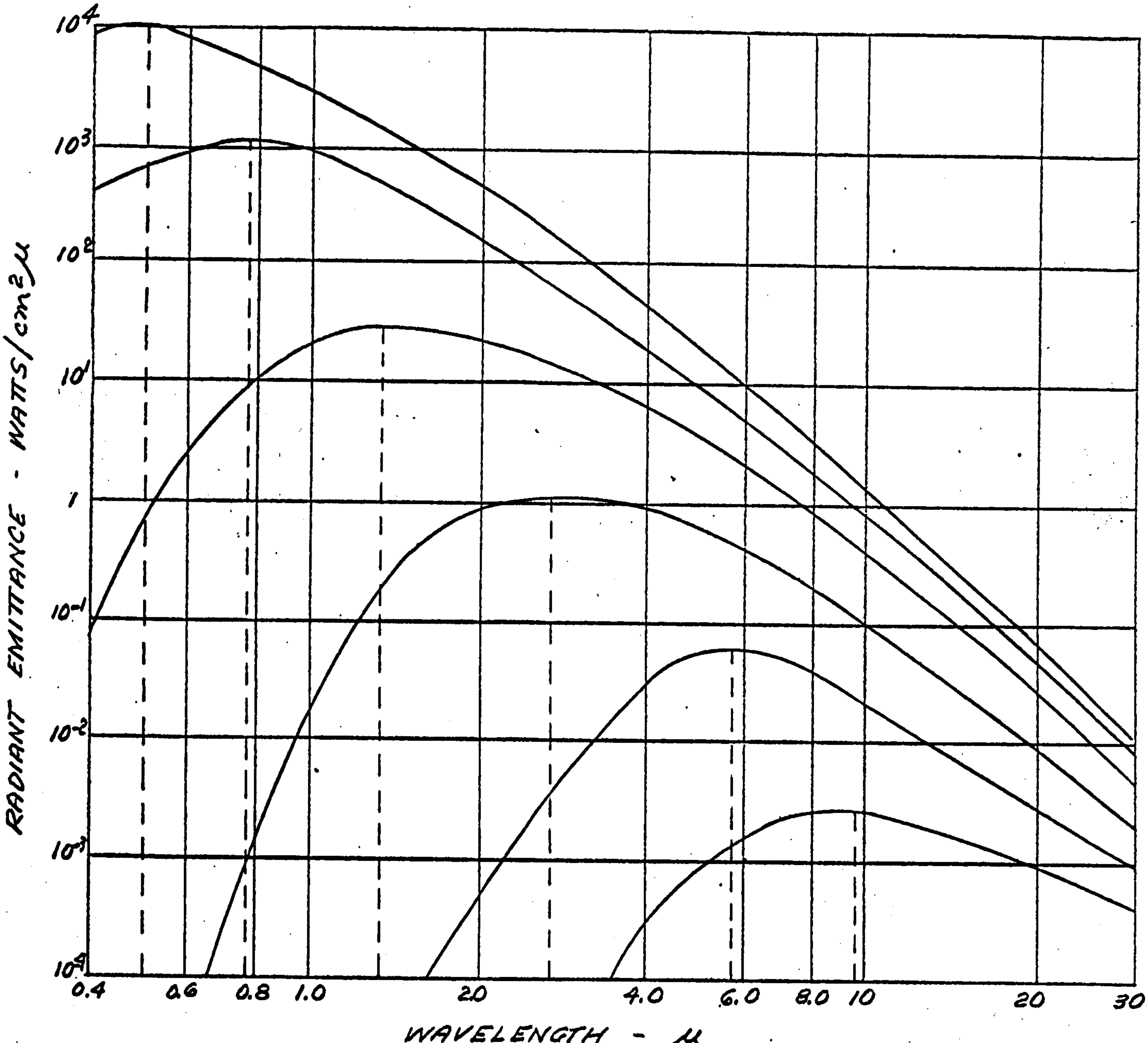
RESISTANCE vs APERTURE AREA

FIG. 8



DYNAMIC IMPEDANCE vs BIAS VOLTAGE

FIG. 9



$\lambda_{MAX.} \cong \frac{3000}{T}$, WHERE λ IS IN MICRONS AND T IS IN DEGREES KELVIN.

BLACK-BODY RADIANT EMITTANCE vs WAVELENGTH

FIG. 10

A P P E N D I X III

SUMMARY OF HELIX DISTORTION STUDY

APPENDIX III

Review of Results of Trial Ray Trace Analysis for the Helix Pair

The reflected rays, $\vec{r}_3$, were intersected with a plane perpendicular to the axis of the incident beam $\vec{r}_1$ having the following equation:

(1) $-\frac{1}{\sqrt{2}}x - \frac{1}{\sqrt{2}}z = 18,$

giving the coordinates X_3, Y_3, Z_3 in the plane of equation (1). An apparent error has occurred in the calculations for ray "1" and "2" intercept on the first helix, the cause of which has not yet been corrected, or found. (The difference in the Y_1 coordinates for rays "1" and "2" is approximately 27.4mm while rays "3" and "4" X_1 values only differ by approximately 9mm, yet the 27.4mm should be the "minor" axis of the approximate ellipse and 9mm the "major" axis.) Nevertheless, the following conclusions are possible from a consideration of the results for rays "0", "3", and "4:"

1. The direction cosines for exit ray "0", $\vec{r}_3$, are not exactly parallel to the entering ray "0", $\vec{r}_1$, and indicate that the polygon axis should be positioned not exactly perpendicular to the axis of helix 1 (the first helix along the optical axis from the lens) if a 45° "incidence" angle for the polygon is intended. The best position for the helix will depend on also checking the beam with the helices rotated 90° and 270°.

2. At this position of the helix, $\theta_1 = 180^{\circ}$, there is approximately an average 1% difference in the distance from ray "0" to "3" compared to from ray "0" to "4", which would indicate an approximate line-to-line change of about on the average .02%, assuming 100 lines per frame.

SUMMARY OF TRIAL

Calculations Performed Using a Ray Trace Analysis For Two Helical Surfaces

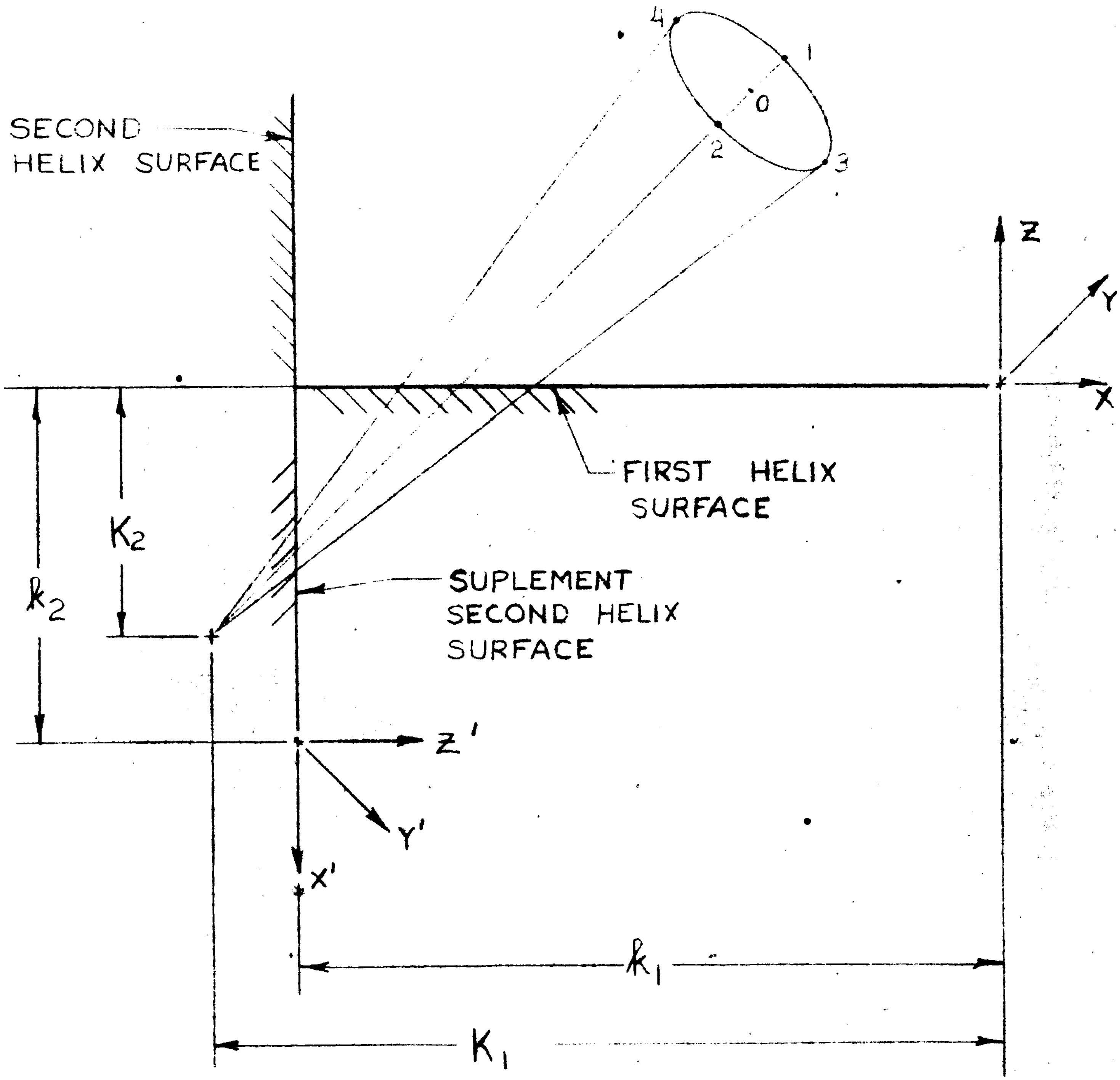
(All distances in millimeters except as noted)

Constants Used:	k_1 = 139.40734mm	$P_1 = P_2$ = .433277mm	K_2 = 37.30786mm
	k_2 = 97.9366mm	K_1 = 165.66904mm	$\theta_1 = 3^\circ\ 19.2'$

$\vec{r_2}$:	Ray 0	Ray 1	Ray 2	Ray 3	Ray 4
cos $\alpha 1$	-.707107	-.70541	-.706434	-.74687	-.664971
cos $\beta 1$	+.004825	-.05315	+.062671	+.004717	+.004931
cos $\gamma 1$	+.707173	+.70677	+.705128	+.664957	+.746858
$\Sigma \cos^2$	1.000113	+.999952	1.000182	1.000003	1.000008
$\theta 1$	180°	$173^\circ 50.25'$	$186^\circ 9.7'$	180°	180°
r1	127.00	127.78379	127.69147	122.23751	131.24026
X1	-127.00	-127.04648	-126.95341	-122.23751	-131.24026
Y1	. 0	13.69906	-13.70512	0	0
Z1	1.36118	1.31458	1.40776	1.36118	1.36118
$\theta 2$	$180^\circ 2.857'$	$182^\circ 35.931'$	$173^\circ 34.33'$	$180^\circ 3.4746'$	$180^\circ .5047'$
r2	-113.0679	-112.597	-113.79	-115.7968	-109.9997
X2	-140.76887	-140.78817	-140.71991	-140.76896	-140.768583
Y2	+.093967	+5.105148	-12.73993	+.1170389	+.01614982
Z2	+15.13126	+14.54425	+15.140278	+17.8602	+12.0631
$\vec{r_3}$: cos $\alpha 2$	+.706998	+.706044	+.699932	+.746819	+.664911
cos $\beta 2$	+.010244	-.047724	+.067995	+.010306	+.010169
cos $\gamma 2$	+.707169	+.706023	+.711121	+.664951	+.746850
$\Sigma \cos^2$	1.000038	+.999245	1.002147	.9990046	.999995
X3	-90.55858	-90.3934	-91.05	-89.214505	-92.140016
Y3	.821486	+1.698	-7.909	.828	.760
Z3	65.353701	+64.9375	65.599098	63.758649	66.684165

SKETCH (NOT TO SCALE) 1-15-65

TO ILLUSTRATE RELATIVE POSITIONING OF HELIXES AND RAY BEAM FOR TRIAL CALCULATIONS



A P P E N D I X IV

DATA SHEETS

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digitork® ENGINEERING BULLETIN NO. 1

THE FIRST INDUSTRIAL DIGITAL MOTOR OF ITS KIND

Combining power and precision in a single flexible control system Pace Controls Corp. has developed a discrete positioner offering the design engineer a new and advanced device for solving problems in precision control and power positioning. We call this DIGITORK.

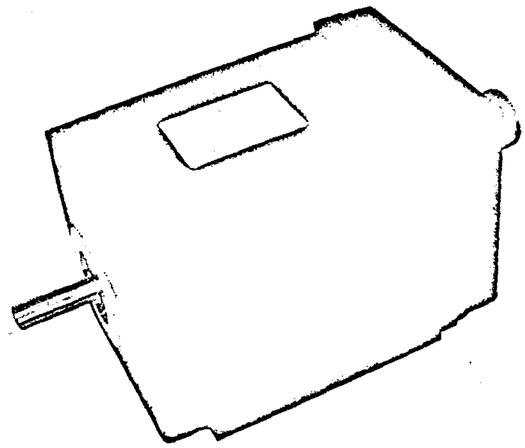
THIS IS DIGITORK

DIGITORK is our trade name for a family of products centered around a unique stepping motor principle. As the name suggests DIGITORK is a digital, torque-producing actuator responding in discrete increments of motion — one step for each pulse. The concept of application in its rudest element is . . . a desired motion — rotary, linear or other — may be accurately controlled by the *number* of pulse signals furnished. The speed of the motion may be accurately controlled by the *rate* at which the signals are delivered to the control.

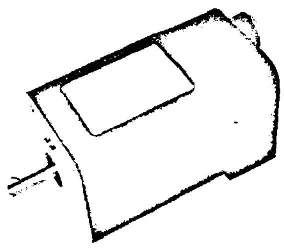
But DIGITORK is more than a measuring device — or positioning controller.

Because DIGITORK is capable of responding accurately to a variety of pulsing rates, it is an infinitely variable speed device . . . yet has the capability of maintaining exact constant speeds. And because DIGITORK is completely digital many units may be operated together from a common signal source, providing perfect synchronism over a wide and readily adjustable range of relative speeds. It is, in fact, an electrical gear system.

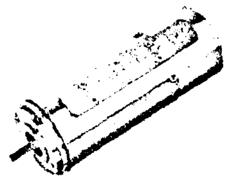
STANDARD DIGITORK MOTORS



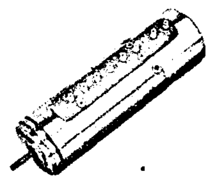
M-60



M-35



M-18



M-15

Although much use of DIGITORK is directed toward controlling functions where response is programmed in advance, application of DIGITORK to indicating or controlling devices from random signal sources is thoroughly practical. The precise digital control feature, rapid response time, and high torque make DIGITORK an ideal actuator for virtually all controlling, regulating, or positioning jobs in process control systems.

HOW DIGITORK WORKS

DIGITORK motors are operated by a control amplifier. The primary function of the amplifier is to receive "metered" pulses from an external source — to shape, amplify and distribute high current pulses to the proper motor windings. The size or shape of input pulses to the control amplifier is not critical and the control power required is but a few microwatts.

Rotation is controlled in discrete increments, the number per revolution depending on the motor design and gearing — (Current motor models have 36, 48 and 108 steps per revolution). In responding to input signals the motor will rotate an exact distance as directed by the number of pulses furnished. The resolution accuracy is plus or minus 10% of one step and is non-cumulative . . . regardless of the number of steps.

In the low frequency range (up to approx. 150 cps) the steps are distinct, and the motor actually comes to rest — between each step — without oscillation. Above this frequency the motor continues to operate in controlled increments but the resulting motion of the shaft is similar to a synchronous motor.

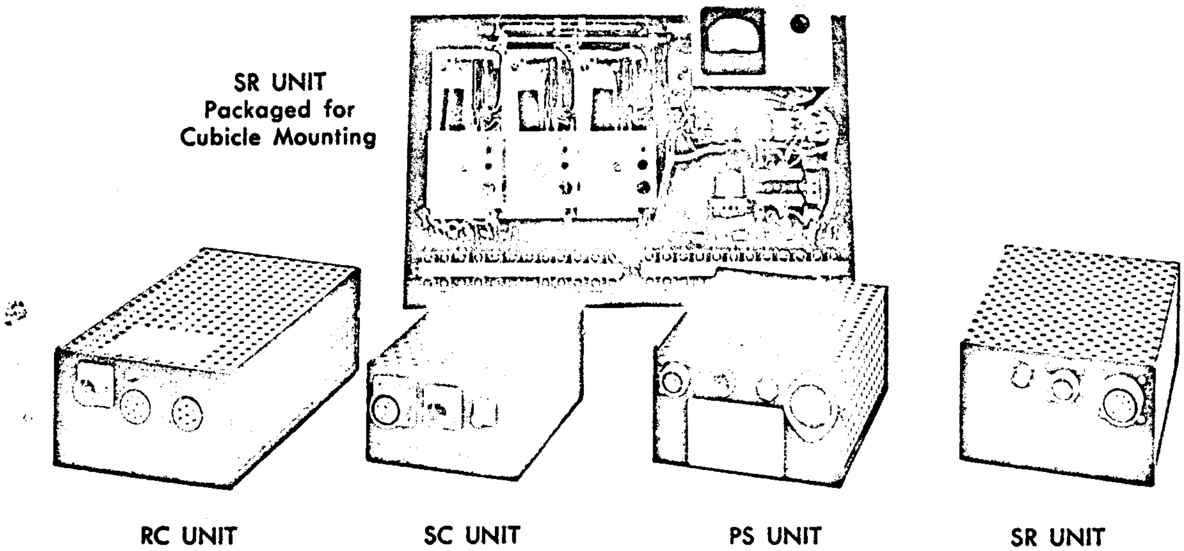
DIGITORK, however versatile, cannot cancel the basic laws of physics . . . to operate above instantaneous start-stop rate it therefore requires programmed (controlled) acceleration and deceleration. In most applications this control feature is relatively simple to provide — in some it is not necessary at all.

The DIGITORK motor — when stopped — will remain locked in position so long as current is on . . . and will remain in this position continuously without overheating.

Through its control amplifier the DIGITORK motor will reverse its operation, having identical performance in either direction. An on-off type of signal will accomplish the reversal . . . using the same pulse source for intelligence in both directions. Instantaneous reversing rates are approximately that of instantaneous starting rates. Both will vary somewhat with load conditions.

The DIGITORK principle — in itself — does not require feedback. The motor, when operated within its range of performance *will not miss steps.* There are applications in which error may be induced by the intelligence (signal input) and others in which the driven mechanism may have backlash . . . or other error-producing characteristics. In such cases, feedback may be provided in one of several forms . . . principally that of matching motion — (in digital increments) with input signals, making a correction if necessary.

In programmed systems or where ample "storage" time is provided, a system may be furnished to correct for backlash wherein the exact position of rest is corrected for in the reverse direction . . . before programmed information is delivered to the motor. This is a patented DIGITORK product.



TYPICAL DIGITORK CONTROLS

DIGITORK has been applied to many complex systems. For example . . . responding to the output of a computer, controlling motions in several axes. Other applications are decidedly less sophisticated or quite simple by normal standards.

The current DIGITORK motor models are designed to be as versatile as possible, consistent with the demands of many industry standards. The two smaller sizes (M15 and M18) are designed in servo mountings — the larger sizes (M35 and M60) in industrial type enclosures. In the near future more styles of motors will be added to our standard line both in high performance precision devices and in less costly commercial designs.

Control components currently available as standard devices consist principally of the control amplifiers designed specifically for the individual standard motor characteristics. Pulsers, shapers, acceleration controls, backlash controls, counting, storage and other devices have been constructed and will be offered to suit individual application requirements. There are no such devices in standard designs at the present.

The design engineer need only use his imagination to conceive of dozens of practical applications using DIGITORK . . . being the first and only torque-producing, digital actuator to operate in a broad range of frequencies.

It is well that some of the distinct features be listed for ready reference — here are a few:

DIGITORK MOTORS ARE . . .

completely digital — converting digital information into digital motion

true motors — not ratchet devices

simple motors — having no commutators, slip rings, or permanent magnets

reversible — having equal response in both directions

versatile — being designed for a wide variety of applications, mountings, environmental conditions

well constructed — of substantial, materials designed with a minimum of wearing parts — the stator sections potted in epoxy resin providing a rigid, non-varying structure.

high performance devices — by present standards . . . no other known device can provide reliably controlled discrete increments of motion — with a usable torque — in frequency ranges to kilocycles

DIGITORK CONTROLS ARE . . .

solid state devices engineered with the latest acceptable techniques in solid state circuitry

well constructed packages made up of quality components thoroughly tested for stability and reliability

versatile providing various ranges of motor performance characteristics to suit individual applications

adaptable — control components are offered in standard units . . . but they may be adapted to a variety of enclosures and mountings to meet specific space or design requirements

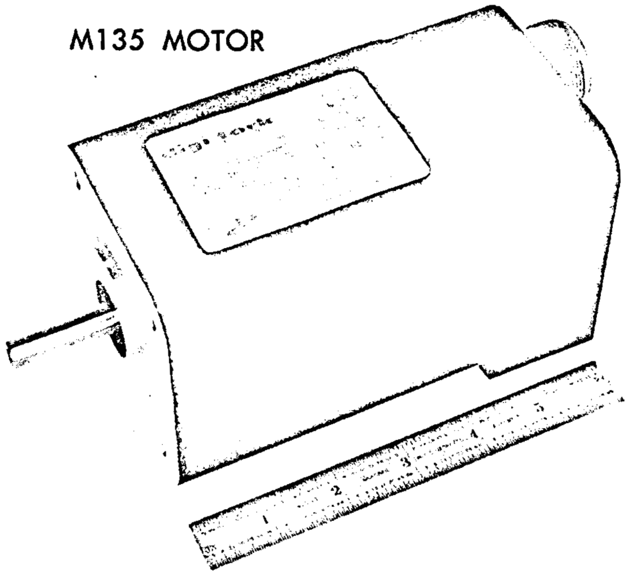
TO APPLY DIGITORK — refer first to Application Data Sheet No. 10—1 describing the DIGITORK system and then to individual data sheets.

electronic engineers master 3500

ENGINEERING DATA SHEET 20-1
STEPPING MOTOR TYPE M135

THE FIRST INDUSTRIAL DIGITAL MOTOR OF ITS KIND

M135 MOTOR



The M135 is a medium size motor mounted in a rugged, industrial type case. It is intended for applications where relatively high torque, medium stepping rates, and hard usage are anticipated. See specification sheet on M160 for higher torque motor, and M115 and M118 sheets for instrument size motors.

PERFORMANCE DATA

SPEED RANGE: 0 - 1500 steps per second (see curve)

RATED TORQUE: 35 ounce inches minimum at 0 - 700 steps per second (see curve)

INSTANTANEOUS STARTING AND STOPPING RATE: 110 steps per second maximum at 35 ounce inches rated load and 0.0068 ounce inch seconds^2 maximum load inertia

AMBIENT TEMPERATURE RANGE: 0 - +55 degrees C

STEPS PER REVOLUTION: 48

DEGREES ROTATION PER STEP: 7.5 degrees nominal

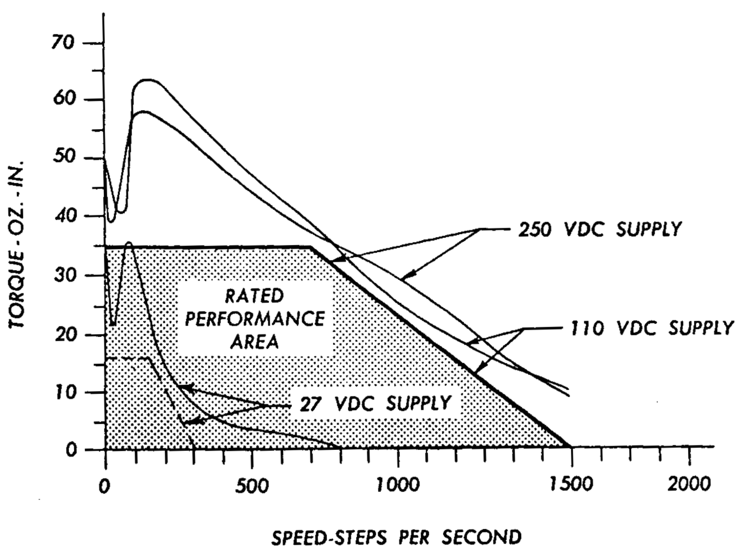
ACCURACY OF STEP POSITION: Position of each individual step ± 45 minutes; cumulative error after each series of 3 steps, negligible

ACCELERATION AND DECELERATION CHARACTERISTICS — See Application Data Sheet 10-3

SHAFT ROTATION: 3 models - clockwise - counter clockwise - reversible

CONTINUOUS DUTY

TORQUE-SPEED CURVES

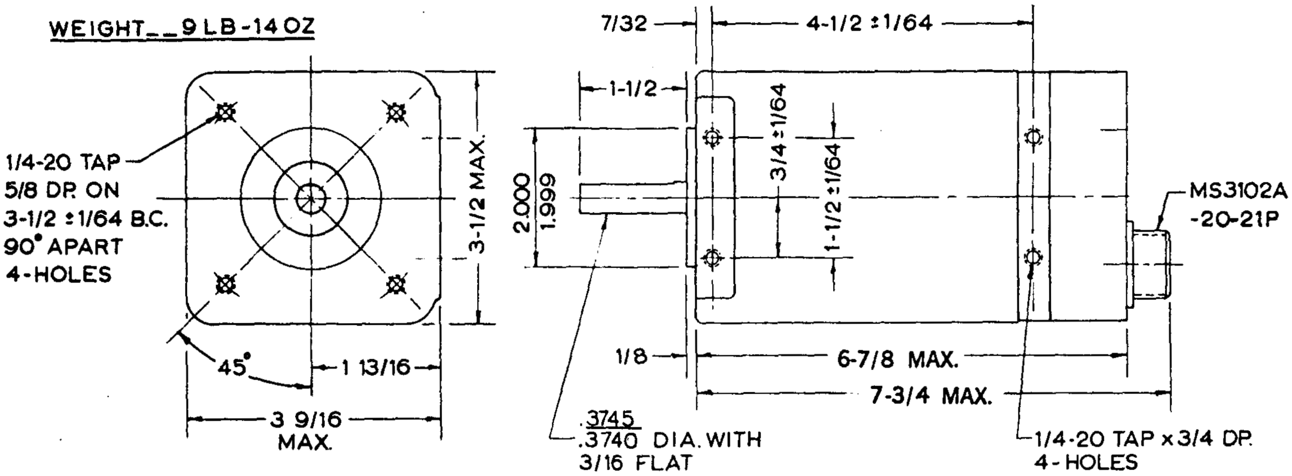


ACE CONTROLS CORP. · NEEDHAM HEIGHTS 94, MASSACHUSETTS

ELECTRICAL DATA

SYSTEM SUPPLY VOLTAGE:	Ranges - 27 VDC to 250 VDC (see table) 115 VAC and 220 VAC (see table)
SYSTEM DC SUPPLY CURRENT:	5 amperes (independent of voltage)
MOTOR POWER DISSIPATION:	100 watts - at rated speed and load
INPUT CONTROL PULSE:	See data sheet on individual Control Unit

OUTLINE DRAWING



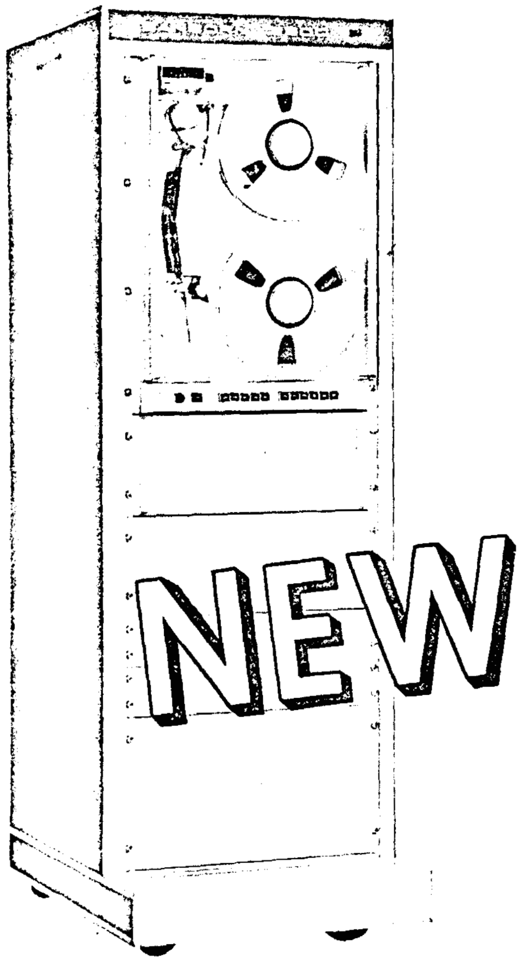
APPLICATION DATA TABLE

		AUXILIARY UNITS — MODEL NUMBERS					
		DC SUPPLY VOLTAGE					
		24 - 30 VDC		100 - 120 VDC		225 - 275 VDC	
MOTOR MODEL #	DIRECTION OF ROTATION	CONTROL UNIT	MATCHING UNIT	CONTROL UNIT	MATCHING UNIT	CONTROL UNIT	MATCHING UNIT
M135AY	Clockwise	SC1AFR	RC35AC1F	SR1AHR	RC35AR1H	SR1AKR	RC35AR1K
M135BY	Reversing	SC1BFR	RC35BC1F	SR1BHR	RC35BR1H	SR1BKR	RC35BR1K
M135CY	Counter Clockwise	SC1AFR	RC35CC1F	SR1AHR	RC35CR1H	SR1AKR	RC35CR1K
		AC SUPPLY VOLTAGE					
		105 - 125 VAC Single Phase			200 - 240 VAC Single Phase		
		CONTROL UNIT	MATCHING UNIT	POWER SUPPLY	CONTROL UNIT	MATCHING UNIT	POWER SUPPLY
M135AY	Clockwise	SR1AHR	RC35AR1H	PS1JHT	SR1AKR	RC35AR1K	PS1LKT
M135BY	Reversing	SR1BHR	RC35BR1H	PS1JHT	SR1BKR	RC35BR1K	PS1LKT
M135CY	Counter Clockwise	SR1AHR	RC35CR1H	PS1JHT	SR1AKR	RC35CR1K	PS1LKT

SANBORN MAGNETIC DATA RECORDING

7- AND 14-CHANNEL SYSTEMS SERIES 3907A, 3914A

S-5M-3-64
S-10M-7-64



- *Tape Deck Especially Designed for Sanborn by Hewlett-Packard*
- *FM, Direct and Pulse Record / Reproduce Electronics*
- *Six Pushbutton Speeds — 1⅞ IPS to 60 IPS with No Capstan Change*
- *Improved Signal / Noise Ratios*
- *Low Wow and Flutter*
- *Built-in Footage Counter*
- *All Solid-State Circuits*
- *Adjustable Input / Output Levels*

BASIC DESCRIPTION

SANBORN Model 3907A and 3914A are two *new* high performance Magnetic Tape Recording Systems designed for use in data recording, storage and reduction systems. The tape transports, designed exclusively for this equipment by Hewlett-Packard, provide improved flutter and distortion specifications; six speeds electrically selected without changing capstan or idler; 4 second max start time, 1 second max stop time; and a built-in footage counter. Both of these compact, versatile and low-cost-per-channel tape systems comply with all IRIG requirements.

Both systems offer interchangeable, FM, Direct and Pulse Record/Reproduce electronics consisting of solid state amplifier inserts and speed equalization plug-ins. All modules are readily accessible on the front panel to change bandwidth for each tape speed change. Each system contains a multi-track tape transport, insert rack and transfer chassis, preamplifier rack, power supply, (7 or 14) reproduce preamplifiers and cabinet. FM, Direct, or Pulse Amplifier Inserts, in any combination, plus appropriate speed equalization plug-ins are added to the basic assemblies.

The new Hewlett-Packard/Sanborn tape transports provide a total of six speeds; 1⅞, 3¾, 7½, 15, 30 and 60 IPS which allow for a maximum time expansion, or time compression of 32 to 1. Transports **also have remote control connector for complete** recorder operation: Stop, Play, Reverse, Fast, Forward and Record. Tape loop adapter, voice channel, and input conditioning circuits are also available.

USES

Sanborn Model 3907A and 3914A 7- and 14-channel tape recording systems are so broadly applicable in both simple and complex recording, storage and data reduction systems that only the more general uses are mentioned here. Major fields include *telemetry, aircraft flight tests, jet and rocket engine tests, and vibration studies.* Optional tape loop attachment and voice channel increase the usefulness of tape systems for data analysis and teaching commentary applications. Direct, FM and Pulse modes permit single-ended input signals to be connected directly — input resistances are 20K, 20K, and 10K ohms, respectively. The input signal level can be 0.5 to 10 V rms on Direct, ±1.2 to ±3 V p to p on FM, and a zero based −7½ to −30 V rectangular pulse on Pulse. Push-pull signals can also be monitored by the tape systems through the use of an optional Sanborn Input Signal Coupler.

Medical researchers, teachers and clinicians will have wide use for the "3907A" and "3914A" in biophysical applications from simple data storage and processing to major physiological data monitoring systems.

DIRECT RECORD/REPRODUCE SYSTEM PERFORMANCE

This system uses a 3900-12A Direct Record/Reproduce Amplifier insert to proportionately record on the tape the AC input signal and when reproduction of this signal is required, reproduce the input AC signal as a proportional output voltage. Frequency compensation to allow for speed changes on all tracks in the *reproduce* mode is provided by individual plug-ins designed to slide into the amplifier inserts. A built-in bias oscillator provides a fixed amplitude high frequency signal which is mixed with the input voltage to compensate for the non-linearity of the tape.

RECORD AMPLIFIER INPUT: 20,000 ohms input resistance, single ended. 0.5 to 10V rms, adjustable.

REPRODUCE AMPLIFIER OUTPUT: Single ended, adjustable from 1V rms to 2.1V rms at ±3 ma. Source impedance 100 ohms max. DC level adjustable ±1.5V.

THIRD HARMONIC DISTORTION: 1% typical at 1KC and 60 IPS.

Tape Speed	Bandwidth	Frequency Response	S/N Ratio Minimum RMS*
60 ips	100–100,000 cps	±3 db	40 db
	300–70,000 cps		45 db
30 ips	100–50,000 cps	±3 db	42 db
	300–35,000 cps		47 db
15 ips	50–25,000 cps	±3 db	42 db
	300–16,000 cps		47 db
7½ ips	50–12,000 cps	±3 db	42 db
	300–7,200 cps		47 db
3¾ ips	50–6,250 cps	±3 db	42 db
	300–3,800 cps		47 db
1⅞ ips	50–3,125 cps	±3 db	40 db
	300–2,200 cps		45 db

*Measured with bandpass filter at output with an 18 db/octave rolloff.

FM RECORD/REPRODUCE SYSTEM PERFORMANCE

This system uses the 3900-13A FM Record/Reproduce Amplifier Insert to convert an input voltage into a frequency which is proportionately related to the reference carrier frequency. Full scale input voltage produces a 40% change in carrier frequency. Signals appearing at the record head are square waves of current, sufficient to cause tape saturation on alternate half cycles. Reproduce head signals are fed into the 3900-10A preamplifier and then to the 3900-13A insert, where they are amplified, clipped and demodulated. Output voltage of the insert is proportional to reproduce frequency and hence, input voltage. An additional plug-in is placed onto the insert to provide suitable modulation and demodulation frequency characteristics and output filtering. A different equalization plug-in is required for each tape speed.

RECORD AMPLIFIER INPUT: Single ended, 20K impedance, ±2.5V DC nominal, adjustable ±1.2V to ±3V.

REPRODUCE AMPLIFIER OUTPUT: Single ended, 100 ohms source impedance maximum, ±2.5V DC nominal (at ±3 ma maximum), adjustable ±1.2V to ±5V. DC position adjustable ±2V.

LINEARITY: DC, ±0.5% of full scale max; AC, ±1% of full scale max.

DRIFT: ±0.25% max for 10°C change, 15°C to 35°C. ±0.25% max for 10V line voltage change.

Tape Speed	Bandwidth	Frequency Response	FM Center Carrier Frequency (Nominal)	S/N Ratio over Bandwidth/Min RMS at 0% Frequency Deviation* Without Flutter Comp	S/N Ratio over Bandwidth/Min RMS at 0% Frequency Deviation* With Flutter Comp**
60 ips	0–10KC	+0, −1 db	54 KC	44 db	48 db
30 ips	0–5KC	+0, −1 db	27 KC	44 db	49 db
15 ips	0–2500 cps	+0, −1 db	13.5 KC	45 db	49 db
7½ ips	0–1250 cps	+0, −1 db	6.75 KC	40 db	47 db
3¾ ips	0–625 cps	+0, −1 db	3.38 KC	42 db	47 db
1⅞ ips	0–312 cps	+0, −1 db	1.69 KC	37 db	41 db

*Measured with lowpass filter at output with an 18 db/octave rolloff.
**Channel 3 and/or 10 provide flutter compensation.

PULSE RECORD/REPRODUCE SYSTEM PERFORMANCE

This system uses a 2000-1400-1 Pulse Record/Reproduce Amplifier Insert to record and reconstitute rectangular pulse signals. The tape is always driven to saturation. Plug-in sub-assemblies are not required for different tape speeds.

RECORD AMPLIFIER INPUT: Rectangular zero-based negative-going pulse, −7½ to −30 volts final amplitude. Rise and fall times are not important except when they influence timing of recorded signal. There is no upper limit on pulse duration.

INPUT RESISTANCE: Single ended, 10,000 ohms.

REPRODUCE AMPLIFIER OUTPUT: Rectangular zero-based negative-going pulse, approx. −11.8 volts final amplitude across open circuit. Output signal amplitudes and rise and fall times are not related to input signals except as noted above.

OUTPUT SOURCE RESISTANCE: Single ended, 1000 ohms; may be loaded. For example, with 1000 ohm load approx. 6 volts is available.

Record and Playback at	Max. Rise Time (micro-sec.)	Min. Input Pulse for Output Pulse Accuracy (Duration) (micro-sec.)	Accuracy of Pulse Reproduction (micro-sec.)	Typ. Min. Input Pulse for any Output (micro-sec.)
60 ips	4	50	±5	10
30 ips	4	100	±10	15
15 ips	5	200	±20	25
7½ ips	10	400	±40	35
3¾ ips	20	800	±80	50
1⅞ ips	40	1600	±160	70

Recording at one speed and playing back at a different speed is possible. Rise time depends on playback speed. Minimum input pulse duration depends on record speed.

TAPE TRANSPORT SPECIFICATIONS

The tape transport provides tape motion for all modes of operation and assures smooth, positive movement of the tape across the head assembly. Operating controls are located on the front panel.

NUMBER OF TRACKS: 7 (Model 3907A), 14 (Model 3914A).

TRACK WIDTH: 0.05″ (both models).

TRACK SPACING: 0.07″ center-to-center (both models).

MAXIMUM INTERCHANNEL TIME DISPLACEMENT ERROR: ±1 microsecond at 60 IPS, between two adjacent tracks on same head (both models).

TAPE SPEEDS: 60, 30, 15, 7½, 3¾, 1⅞ inches per sec. (both models).

TAPE WIDTH: ½″ (Model 3907A), 1″ (Model 3914A).

TAPE THICKNESS: 1.5 mil, 1.0 mil or 0.65 mil (both models) (1.0 mil preferred).

TAPE LENGTH: 2400 feet — 1.5 mil tape; 3600 feet — 1.0 mil tape. 4800 ft. — 0.65 mil tape (both models).

REEL SIZE: 10½″ NAB (both models) or Precision (Precision preferred).

START TIME: Approx. 4 sec. max.

STOP TIME: 1 second max.

REWIND TIME: Approx. 100 seconds for 2400 feet and 150 seconds for 3600 feet of tape (both models).

CONTROLS: Operating controls — Line (Power), Stop, Play, Reverse, Forward (fast), Record, are pushbutton relays. A receptacle at the rear of the transport is provided for remote control operation.

DRIVE SPEED ACCURACY: ±.25% of nominal capstan speed, (both models) which is directly proportional to line frequency.

SYSTEM WEIGHT: Approximately 310 lbs. net, both models.

SYSTEM DIMENSIONS: 57¾″ high x 22″ wide x 26″ deep (both models).

SYSTEM POWER REQUIREMENTS: 105 to 125 volts RMS 60 cps ±2 cps. Approx. 500 watts (both models).

FLUTTER
(both models)

Speed	Bandwidth	Flutter (p-p)
60 ips	0–200 cps	0.2%
	0–1.5 KC	0.3%
	0–10 KC	0.6%
30 ips	0–200 cps	0.2%
	0–1.5 KC	0.5%
	0–5 KC	0.8%
15 ips	0–200 cps	0.25%
	0–1.5 KC	0.45%
	0–2.5 KC	0.6%
7½ ips	0–200 cps	0.4%
	0–1.25 KC	0.65%
3¾ ips	0–200 cps	0.5%
	0–625 cps	0.8%
1⅞ ips	0–200 cps	0.8%
	0–312 cps	1.2%

REPRODUCE AMPLIFIERS

A preamplifier card provides the first three stages of amplification for the reproduce section of a record/reproduce channel. There are 7 preamplifier cards for the Model 3907A system and 14 preamplifier cards for the Model 3914A system.

INSERT RACK AND TRANSFER CHASSIS

Each insert rack and transfer chassis contains a power supply and accommodates up to seven record/reproduce amplifier inserts complete with equalization plug-ins.

POWER SUPPLY

The Power Supply, located on the Insert Rack and Transfer Chassis, delivers regulated operating voltages to all electronic circuits of the recording system. Supply voltages can be measured at test points on the front panel. A built-in meter and a selector switch is used for alignment of all FM channels, eliminating the need for electronic counters.

PRICES BASIC ASSEMBLIES

MODEL 3907A, 7 track Basic System with provisions for additional monitoring track. Consists of 6 speed tape transport (1⅞, 3¾, 7½, 15, 30, 60 IPS), Insert Rack and Transfer Chassis, Power Supply, Preamplifier Rack, (7) Reproduce Preamplifiers and Mobile Cabinet **$6,185.00**

MODEL 3914A, 14 track Basic System with provisions for additional monitoring track. Consists of 6 speed tape transport (1⅞, 3¾, 7½, 15, 30, 60 IPS), (2) Insert Racks and Transfer Chassis, (2) Power Supplies, (2) Preamplifier Racks, (14) Reproduce Preamplifiers and Mobile Cabinet **8,415.00**

OPTION 1 FOR MODELS 3907A AND 3914A
Same as Models 3907A and 3914A less cabinet, but including all the necessary hardware for rack mounting in 19" racks.

- Model 3907A, Option 1 .... **5,680.00**
- Model 3914A, Option 1 .... **7,910.00**

OPTION 2 FOR MODELS 3907A AND 3914A
Same as Models 3907A and 3914A except systems are mounted in portable cabinets.

- Model 3907A, Option 2 .... **6,185.00**
- Model 3914A, Option 2 .... **8,415.00**

OPTION 3 FOR MODEL 3907A, 7 track Basic System, same as above, less monitoring track provisions (when available) .... Subtract **135.00** from any of the above

OPTION 3 FOR MODEL 3914A, 14 track Basic System, same as above, less additional monitoring track (when available) .... Subtract **135.00** from any of the above

ELECTRONICS

Add to the Basic Assembly the number of FM, Direct, or Pulse Reproduce Inserts required (each active channel will require one Insert according to the recording requirements).

- **Model 3900-12A Direct Record-Reproduce Insert** .... **$155.00 ea.**
- **Model 3900-13A FM Record-Reproduce Insert** .... **180.00 ea.**

For each Model 3900-12A Insert depending on the tape speeds to be used — select from the following plug-ins:

- 1⅞ IPS — Model 2000-1200-C2 Direct Equalization Plug-in **35.00**
- 3¾ IPS — Model 2000-1200-C3 Direct Equalization Plug-in **30.00**
- 7½ IPS — Model 2000-1200-C4 Direct Equalization Plug-in **30.00**
- 15 IPS — Model 2000-1200-C5 Direct Equalization Plug-in **30.00**
- 30 IPS — Model 2000-1200-C6 Direct Equalization Plug-in **30.00**
- 60 IPS — Model 2000-1200-C7 Direct Equalization Plug-in **30.00**

For each Model 3900-13A Insert depending on the tape speeds to be used — select from the following plug-ins:

- 1⅞ IPS — Model 2000-1300-C2 FM Frequency Plug-in **60.00**
- 3¾ IPS — Model 2000-1300-C3 FM Frequency Plug-in **40.00**
- 7½ IPS — Model 2000-1300-C4 FM Frequency Plug-in **40.00**
- 15 IPS — Model 2000-1300-C5 FM Frequency Plug-in **40.00**
- 30 IPS — Model 2000-1300-C6 FM Frequency Plug-in **40.00**
- 60 IPS — Model 2000-1300-C7 FM Frequency Plug-in **40.00**

MODEL 2000-1400-1 PULSE RECORD-REPRODUCE INSERT (No Plug-in required) **60.00**

OPTIONAL EQUIPMENT

Input Signal Coupler Model 3907-07A — to adapt equipment with push-pull output to single-ended input of the 3900 series electronics; it occupies 3½ inches of vertical panel space below record-reproduce amplifier panel **395.00**

A plug-in depending on signal source is required for each active channel (see local field office for information) ....

Remote Control Panel Model 3907-11A — control box and cable for remote control of tape transport STOP, PLAY, REVERSE, FAST FORWARD and RECORD functions (less cable) **100.00**

Voice Channel Amplifier Model 3907-06A for recording pertinent commentaries on the data being recorded, includes microphone **250.00**

Note 1: When used with Models 3907A and 3914A for monitoring on the additional track another Reproduce Preamplifier ($40.00), one Direct Insert ($155.00) and one Direct Equalization Plug-in (Price is determined by the speed used) are required.

Note 2: When used with Option 3 of either system where no provisions for an additional channel are included, one of the standard 7 or 14 tracks must be used with a Direct Insert and Equalization Plug-in.

MAGNETIC TAPE: ACCESSORY ITEMS

37T-4	½ Inch, 1 Mil Polyester Heavy Duty Instrumentation Tape, 3600 Feet, Supplied On NAB Reels	1-9	35.35
		10-49	33.40
		50 & over	31.40
37T-5	½ Inch, 1.5 Mil Polyester Heavy Duty Instrumentation Tape, 2500 Feet, Supplied On NAB Reels	1-9	27.00
		10-49	25.45
		50 & over	31.40
37T-9	1 Inch, 1 Mil Polyester Heavy Duty Instrumentation Tape, 3600 Feet, Supplied On NAB Reels	1-9	64.60
		10-49	61.15
		50 & over	57.75
37T-10	1 Inch, 1.5 Mil Polyester Heavy Duty Instrumentation Tape, 2500 Feet, Supplied On NAB Reels	1-9	49.90
		10-49	47.20
		50 & over	44.50

Empty Reels:
- 37T-3 ½ Inch, NAB **7.75**
- 37T-14 ½ Inch, Precision **29.50**
- 37T-8 1 Inch, NAB **13.25**
- 37T-15 1 Inch, Precision **32.00**

Splicing Tape:
37T-7 ½ Inch, Mylar, 100 Feet **1.55**

Bulk Eraser:
48A-13 (Cinema Type 9205A) **102.50**

Head Demagnetizer:
48A-14 (Robins Type HD-6) **12.50**

Tape Splicer:
48A-15 ½ Inch, (Robins Type TS-500) **77.50**

Cabinet Dust Cover:
01060-69010 Gabardine, For 3907A and 3914A. **17.00**

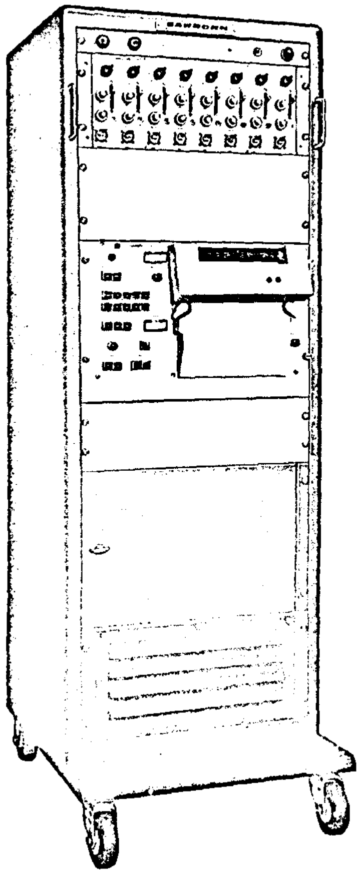
Prices are F.O.B. Waltham, Massachusetts, except accessory items which are priced F.O.B. Destination.

DIRECT-WRITING OPTICAL OSCILLOGRAPHIC SYSTEMS
4500 SERIES

SANBORN

F10M-3-64

6265



Operating and Performance Features

- *Up to 25 Channels*
- *DC to 5 KC Response With one Basic Galvanometer*
- *Choice of 4 Amplifiers: Galvanometer Driver, Low Gain, Medium Gain, Carrier*
- *Sensitivities 500 μv/in to 500 mv/in*
- *Recording to 8" Amplitudes*
- *No Mechanical Galvanometer Positioning*

BASIC DESCRIPTION

SANBORN 4500 Series optical oscillograph system is a completely integrated amplifier-galvanometer-recorder system. Multi-channel amplifiers and galvanometers are matched and packaged to provide an exceptionally convenient, high frequency response recording system.

0 to 5 KC signals can be connected directly to the amplifier front or rear panel and immediately recorded on the 8" wide chart — no time consuming special interconnecting circuits are necessary. Four multi-channel amplifiers cover a sensitivity range from 500 μv/in to 500 mv/in. In addition, each amplifier channel has a front panel "Position" control capable of moving the trace anywhere on the chart without mechanical adjustment. And the optical galvanometers are rugged and relatively inexpensive.

The individual amplifier/galvanometer channels include a special frequency boost and compensation circuit that extends the response of the basic 2KC optical element to 5 KC (−3 db).

Frequency boost and compensation in the amplifier galvanometer circuits permits greater deflection at any frequency than is possible when galvanometers with higher natural frequencies are used. This technique eliminates temperature controlled galvanometer magnet blocks and saves setup time because it eliminates changing and aligning the galvanometers every time the equipment is required to record under conditions of different frequencies and sensitivities.

USES

The 4500 Series system provides permanent records of variables in the 0 to 5000 cps range. It will monitor and record temperature, pressure, force, displacement, strain, computer outputs, telemetry outputs, power supply outputs, etc. It is used in missile and engine analysis, analog recording, production testing, control applications and nuclear tests.

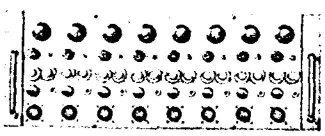
Wherever high speed transient information is needed, the 4500 is especially useful and in all multi-channel applications, where signals having different frequencies (0-5000 cps) are being recorded, the Sanborn "system" concept has the added advantage of avoiding any time delay errors between channels. This is because Sanborn provides you with a system that has the same time delay and frequency response on all channels.

SYSTEM SPECIFICATIONS (Classified By Amplifier Type)

AMPLIFIER MODEL	GALVANOMETER DRIVER GENERAL PURPOSE 656-2000/658-2000	LOW GAIN GENERAL PURPOSE 656-2900/658-2900	MEDIUM GAIN GENERAL PURPOSE 656-3400/658-3400	CARRIER 656-1100/658-1100
SENSITIVITY (Max)	625 mv/1″ (5 v for 8″ trace)	50 mv/1″ (400 mv for 8″ trace)	2.5 mv/1″ (20 mv for 8″ trace)	500 µv/1″, for in-phase component (4 mv for 8″ trace)
SENSITIVITY RANGE (Attenuation)	xl, 2, 4, 10, 20, 40. Smooth gain 2½ to 1 adj. Up scale and down scale output sw. Att. error ±2% max.	x1, 2, 5, 10, 20, 50, 100, 200, 500, 1,000. Smooth gain 2½ to 1 adj. Att. error ±2% max.	x1, 2, 5, 10, 20, 50, 100, 200, 500, 1,000, 2,000, 5,000. Smooth gain 2½ to 1 adj. Att. error ±3% max.	x1, 2, 5, 10, 20, 50, 100 and 200. Smooth gain 2½ to 1 adj. Att. error ±3% max.
INPUT CIRCUIT	Single ended, 100,000 ohms	Bal to gnd, 1 megohm each side	Floating and guarded 100,000 ohms	13K min. resistance, 15K min. reactance } measured with full zero suppression and full R&C Bal 18K resistance, 15K reactance } with zero suppression out and R&C Bal controls centered
COMMON MODE REJECTION RATIO (Min)	N/A	34 db x1 range 28 db other ranges	140 db @ dc 120 db @ 60 cps bal 110 db @ 60 cps 1000 ohms unbal.	N/A
COMMON MODE VOLTAGE (Max)	N/A	±2.5 volt on x1 range, multiply att. range x2.5 to max. of ±500 volts	±500 volts	N/A
FREQUENCY RESPONSE (Within 3 db point)	0 to 5 KC (4″ p-to-p) 0 to 3 KC (8″ p-to-p)			
RESPONSE TIME (10% to 90%)	80 µ Sec. 4% or less overshoot			
DRIFT Max. per 10°C change Line Voltage May be additive	.025″ max., 0° to 50° 0.01″ max., 103 to 127 volts	0.1″ max., 0° to 50°C 0.02″ max., 103 to 127 volts 0.1″ per hour	0.05″, 0° to 50°C 0.01″ max., 103 to 127 volts	0.05″ max., 0° to 50°C 0.1″ max., 103 to 127 volts
GAIN STABILITY Temp. Line Volts	Better than 1%, 0 to 50°C Better than 1%, 103 to 127 volts			
NOISE (Max.)	0.01″ p-to-p max.	0.02″ p-to-p max.	0.02″ p-to-p max.	0.02″ p-to-p max.
CARRIER (Frequency and Volts)	N/A	N/A	N/A	20 KC @ 4.5 to 5 volts (internal)
CALIBRATION	2½ volts ±1%	0.2 volt ±1%	10 mv ±2%	0.4 mv/volt of excitation, ±2%
POWER	115 volts ±10%, 60 cps, 575 watts (complete 8-channel system). 115/230 volts, 50 cps operation available on special order.			

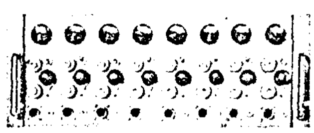
AMPLIFIER FRONT PANEL CONTROLS

MODEL 656-2000 or MODEL 658-2000



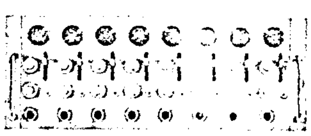
Range (6 positions plus Cal and Off), Gain, Position, Upscale/Downscale, Balance.

MODEL 656-2900 or MODEL 658-2900



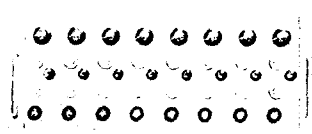
Range (10 positions plus Cal and Off), Gain, Position, Amplifier Balance, Position and Calibrated Zero Suppression Potentiometer and Zero Suppression switch (+ or —).

MODEL 656-3400 or MODEL 658-3400



Range (6 positions and Off), Gain, Function (Use X1, Use X100, Zero and Cal) and Position.

MODEL 656-1100 or MODEL 658-1100



Range (9 positions plus Cal and Off), Gain, Position, Use/Bal switch, Zero Suppression switch (Five step switch, center out, 2 positions each for both positive and negative signal). R-Bal (used also as vernier zero suppression) and C-Bal.

A common power supply at rear of amplifier supplies power for all channels.

INPUT SIGNAL CONDITIONING MULTI-CHANNEL AMPLIFIERS

Each amplifier assembly consists of 6 or 8 identical transistorized channels of amplification and a common power supply. Your signals can be applied directly to the connectors on the front panel or at the rear. The controls on the front panel offer complete operational adjustment whether the amplifiers are to be used in-line or in laboratory applications, without adding costly and complicated input attachments.

Amplifier components for each channel are mounted on a single plug-in circuit board, easily accessible and removable. Matching networks between the amplifier channels and galvanometers are also mounted on plug-in boards. Unlike many optical systems, no temperature controlled galvanometer magnet blocks are required in the "4500" recorder — use of current feedback in the amplifier/galvanometer matching network stabilizes the frequency response of the galvanometer over a very broad temperature range. These multi-channel amplifiers can be used with other optical recorders. For further information please contact your local Hewlett-Packard Field Office or contact Sanborn Company directly.

COMMON SPECIFICATIONS ALL AMPLIFIERS

with Sanborn 9B-1A Galvanometers

FREQ. RESPONSE: DC-5000 cps (−3DB) @ 4" P-P.

OUTPUT: ±72 ma to drive standard 2000 cps galvanometers, 17-ohm nominal load, ungrounded, approx. 10,000 ohms source impedance. Current is limited to ±150 ma.

LINEARITY: 1½% of full scale (8 in.)

INPUT CONNECTORS: Paralleled connectors on front and rear panels, separate connectors for each channel. Guard circuit connection is provided on Model 658-3400. All mating connectors are supplied.

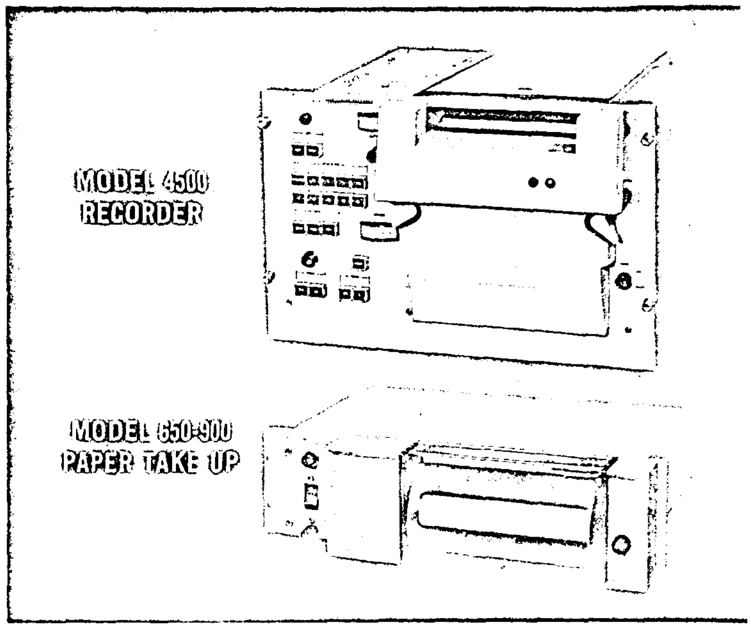
OUTPUT MONITOR: Monitor output jack on front panel provides approximately ±1 volt full scale across 100,000 ohms minimum load (except on Model 658-2000).

POWER: 115 volts ±10%, 50-400 cps, 125 watts; 115/230 volt operation available on special order.

HIGH AMPLITUDE, HIGH FREQUENCY RESPONSE RECORDER

Recordings on the Sanborn "4500" Recorder are made on eight-inch wide ultraviolet sensitive, self-developing photographic paper which is easily loaded in normal room light through a hinged front panel door. Pushbuttons permit convenient selection of nine paper speeds from 0.25 to 100 inches per second. A fluorescent lamp speeds development so that the trace is fully developed in several seconds after exposure. The recording may be photographically "fixed" and with normal care will last indefinitely. Traces may overlap at amplitudes up to eight inches. Additional features include: full width time lines, amplitude lines (removable over part or all of paper), sequential light beam interruption for trace identification, event marker, a lamp power control and meter, and a meter for indicating remaining paper footage. As in most Sanborn recording systems, the "4500" has provision for complete remote operation.

The Paper Take-Up Model 650-900, shown below, is designed to fit below any Model "4500" Recorder. Complete control of the paper and take up speed is automatic from the push button controls on the front panel. A unique clutch mechanism keeps the paper taut at all speeds and a relay automatically stops the take up mechanism at the end of the roll.



RECORDING CHANNELS: One to 25 channels.

PAPER SPEEDS: 0.25, 0.5, 1.0, 2.5, 5.0, 10, 25, 50, and 100 inches/sec. Paper speeds are pushbutton selected.

TIMING LINES: 0.01 or 0.1 second intervals full width across the chart.

AMPLITUDE LINES: 0.1 inch intervals. Can be eliminated over ¼, ½ or total width of chart. Amplitude lines ruled in millimeters or logarithmically are available.

REMOTE CONTROL: A connector is provided to allow remote control of chart speeds, timing and chart drive motor operation. An external remote control panel is available.

GALVANOMETER: Model 9B-1A (standard). Undamped natural frequency is 2000 cps. Frequency response is flat within ±5% to 1200 cps. Sensitivity is 17.5 ma/inch. Nominal coil resistance is 17 ohms. Maximum safe current is 150 ma. Following is a list of additional Galvanometers which are available from Sanborn for situations where the signal is to be fed directly to the recorder: 200cps-9B-1B, 500cps-9B-1C, 3,400cps-9B-1D, 10,000cps-9B-1E, 40cps-9B-1F, 60cps-9B-1G, 100cps-9B-1H, 150cps-9B-1J, 300cps-9B-1K, 900cps-9B-1L, 1,500cps-9B-1N, 3,000cps-9B-1P, 5,000cps-9B-1S, 8,000cps-9B-1T, 1,000cps-9B-1V. For further information on these additional Galvanometers, please contact your nearest HP Field Office or contact Sanborn Company directly.

CONTROLS: Power ON/OFF, Timing Interval Selector, Lamp Power Adjust, Lamp OFF/START, Paper Footage Indicator, Event Marker, Paper Drive ON/OFF/JOG Pushbutton. All controls are on front panel.

VIEWING: Calibrated periscope on front panel allows viewing the traces when recording or calibrating.

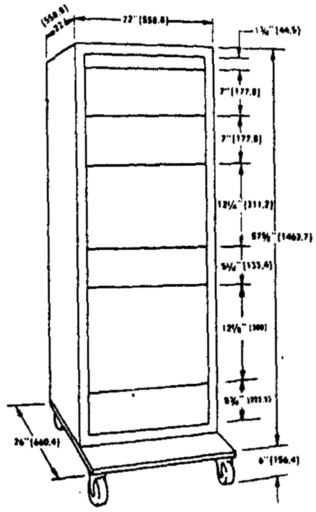
DIMENSIONS: Recorder — 12½" high (317, 5) x 16½" (419, 1) deep x 19" (482, 6) wide. Paper Take-Up — 5½" (139, 7) high x 12" (304, 8) deep x 19" (482, 6) wide.

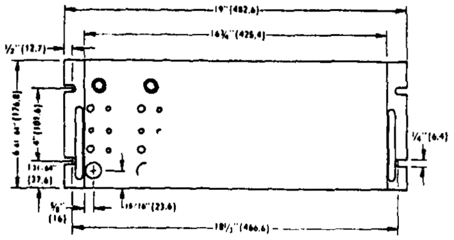
POWER: Recorder — 105 to 125 volts, 60 cycles, 450 watts. Paper Take-Up — 105 to 125 volts, 60 cycle, 195 watts (115/230 volt, 50 cps operation available on special order for both).

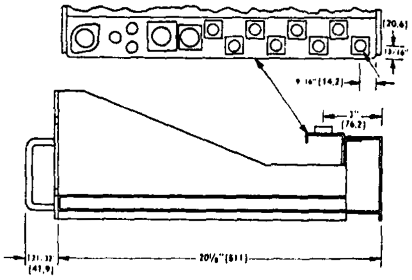
WEIGHT: Recorder — 90 (40, 5) lbs. net, 150 (67, 5) lbs. gross
Paper Take-Up 28 (12, 6) lbs. net, 35 (15, 8) lbs. gross

DIRECT-WRITING OPTICAL OSCILLOGRAPH

GENERAL INSTALLATION DATA







NOTE: The cabinet which is shown (Model 658-1400 used for up to 16 channels) has total rack space of 54⅛" (1374, 7). Cabinet Model 658-2400 (used for up to 25 channels) has an additional 10⅝" (270) of rack space. 7" (177, 8) of the additional space is used for the 3rd amplifier.

AMPLIFIER WEIGHT: 80 lb (36) (658-2000, -2900, -2900A, -3400), 85 lb (38, 3) (658-1100).

AMPLIFIER SHIPPING WGT: 90 lb (40, 5) (658-2000, -2900, -2900A, -3400), 95 lb (47, 8) (658-1100).

AMPLIFIER COOLING: A minimum air flow of 20 CFM through the channel on the rear of the amplifier is required to keep the temperature of the amplifier within operating limits. When the amplifier or systems are purchased without a Sanborn cabinet and air-cooling blower, proper operational ambient temperature becomes the responsibility of the user. In such instances, and where the cabinet being used has sufficient depth (23 inches), Sanborn can install a blower on the rear of the amplifier for $145.00. To order an amplifier with this blower assembled, simply add a "-3" after the amplifier model number.

SYSTEMS AVAILABLE

RECORDERS:

MODEL 4508A, 8 galvanometer block	$3,200
MODEL 4514A, 14 galvanometer block	3,300
MODEL 4518A, 18 galvanometer block	3,300
*MODEL 4524A, 25 galvanometer block	3,400
Galvanometer Model 9B-1A (2000 cps)	125 ea.

*25 galvos are available, one may be driven directly or with an external amplifier.

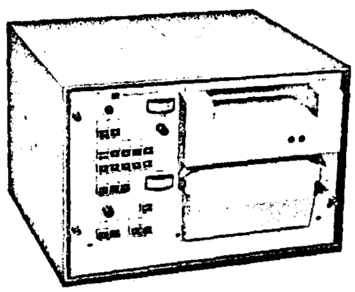
AMPLIFIERS (GENERAL PURPOSE)

MODEL 656-2000 6-channel Galvanometer Driver	$2,000
MODEL 658-2000 8-channel Galvanometer Driver	2,200
MODEL 656-2900 6-channel Low Gain	2,495
MODEL 658-2900 8-channel Low Gain	2,895
MODEL 656-3400 6-channel Medium Gain	3,230
MODEL 658-3400 8-channel Medium Gain	3,780

AMPLIFIER (CARRIER)

MODEL 656-1100 6-channel Carrier	3,400
MODEL 658-1100 8-channel Carrier	3,900

PORTABLE SYSTEMS

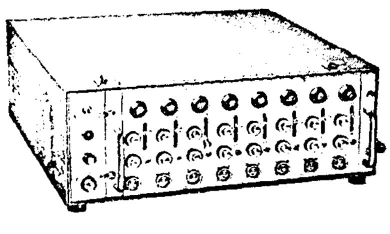


Portable Recorder Carrying Case*

Model 650-1400 .... **$150**

DIMENSIONS: 20³⁄₁₆" (512, 6) wide x 13⁵⁄₁₆" (338) high x 17¾" (450, 9) deep

Shipping wt. (including recorder) .... (95, 4) 212 lb



Portable Amplifier Carrying Case

Model 858-1400 .... **$150**

DIMENSIONS: 22" (558, 8) wide x 7⁹⁄₁₆" (192, 6) high x 21½" (546, 1) deep

Shipping wt. (including amplifier) .... (63) 140 lb

*Portable case for recorder and Model 650-900 Paper Takeup on special order **$200**

UPRIGHT CABINETS

(Complete with Master Control Panel and Blower System)

Model 658-1400 (for up to 16 channels) **$550**

Model 658-2400 (for up to 24 channels) **$600**

ACCESSORIES

RECORDING PAPER

3A-26 200 ft Roll (standard base) .... **$21.65 ea.**

3A-27 350 ft Roll (thin base) .... **35.00 ea.**

DUMMY GALVANOMETERS

A Dummy Galvanometer may be used for each unused position in the galvanometer block. A brass insert is provided at no charge for unfilled galvanometer positions.

Model 9B-1R Dummy Galvanometer with mirror .... **$33 ea.**

Model 9B-1W Dummy Galvanometer without mirror .... **$9.15 ea.**

PAPER TAKEUP

Model 650-900 PTU **$570**

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A P P E N D I X V

HOW TO MOVE AN OPTICAL FIELD ON A SAWTOOTH PATTERN AVOIDING ALTERNATING MOTION AND RETURN LOSSES

A P P E N D I X V

HOW TO MOVE AN OPTICAL FIELD ON A SAWTOOTH PATTERN AVOIDING ALTERNATING MOTION AND RETURN LOSSES

The major difficulty in the design of a fast scanning infrared microscope is the extremely low level of radiating energy emitted from the target. Consequently, every effort must be made to reduce the losses (i.e., to increase the efficiency) of all the elements of the microscope. For the scanning system, the maximum efficiency is obtained when the motion of the reflecting surfaces is linear and no time is lost for the return motion. For instance, a system affected by both such losses is the one shown in Figure 1.

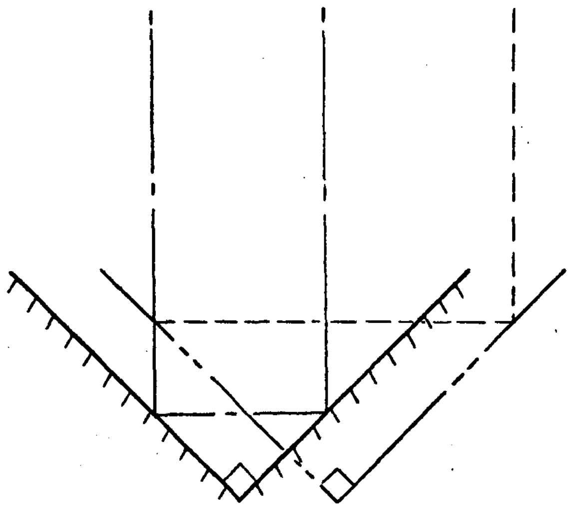

FIG. - 1

This system is composed of two flat mirrors rigidly tied together at 90° angle. It can be seen that a horizontal motion of this pair of mirrors by <u>one unit</u> in length produces a <u>two unit</u> displacement of the outgoing ray, without any change in optical path length (i.e., without shift of the focal plane). Such an optical arrangement could be used in a scanning device, to move the optical field back and forth without focal or distortion aberrations. But due to the fact that the mirrors are not weightless, their speed cannot be linear. Also, if we want to achieve only <u>unidirectional</u> scanning the return motion must be blanked out, with consequent loss of the energy transmitted during this period of time. So, our problem can be stated: "how to achieve a linear speed for the motion of an assembly of two orthogonal mirror surfaces and furthermore how to eliminate the time loss for their return motion."

Figure 2 shows the solution: two rotating wheels have mounted on the side of their outer rims two helicoidal surfaces, whose pitch equals the displacement that the mirrors must travel, as per Figure 1. These helicoidal surfaces are continuous, except for one single step, whose height equals the pitch. The two wheels are always rotating in perfect synchronism, and we phased in such a way that the two steps face each other once every turn. If we observe the displacement of the reflecting surfaces in the plane passing through the axes of rotation of both wheels, we notice that for every turn (starting from the position where the two steps are facing each other) the two reflecting surfaces move in the X direction at uniform speed (for uniform rotational speed of the wheels) and at the end of a 360^{o} revolution of the wheels they fly back in no time to the starting position.

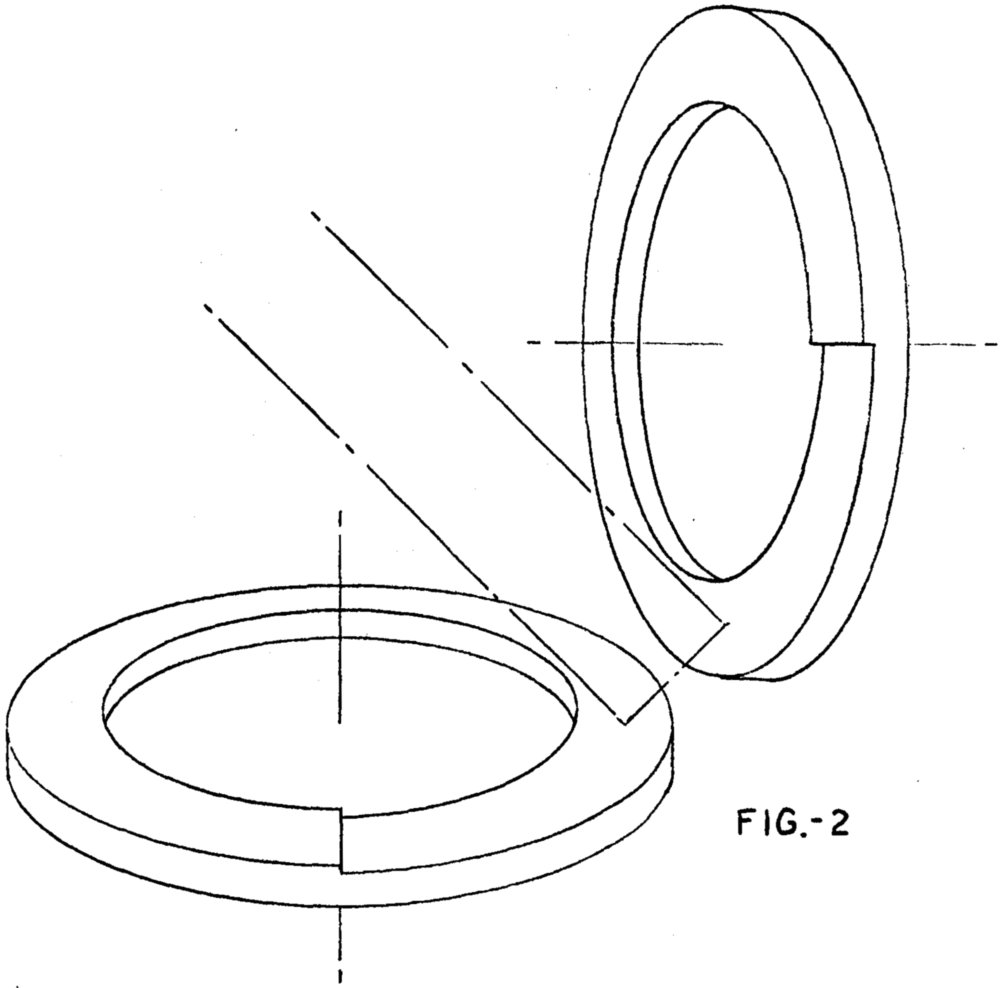

FIG.-2

This solution allows us to achieve a perfect sawtooth displacement of the incoming optical ray, with linear speed and zero return time. If the incoming optical field is composed of many rays instead of a single one, the time lost for the return is equal to that fraction that it takes for the step in the helical surface to cross the whole optical beam.

Optical Distortion of the System

For a single ray there is no distortion. For an optical field reflected by a finite area of the mirrors, there is distortion, due to the fact that the helicoidal surfaces are not true planes. The amount of distortion can be largely compensated by locating the two helices in such a way that the outside rim of one faces the inside rim of the other, and vice versa. Extensive calculations of the residual amount of distortion left in the system under this configuration have been made and they show that this quantity can be controlled by the ratio between the pitch of the helices, the diameter of the wheels and the area intercepted by the reflected optical beam.